TENNESSEE VALLEY AUTHORITY
River Operations

Study to Confirm the Calibration of the Numerical Model for the Thermal Discharge from Sequoyah Nuclear Plant as Required by NPDES Permit No. TN0026450 of September 2005

WR2009-1-45-150

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EXECUTIVE SUMMARY

The National Pollutant Discharge Elimination System (NPDES) permit for Sequoyah Nuclear Plant (SQN) identifies the release of cooling water to the Tennessee River through the plant discharge diffusers as Outfall 101. The primary method to monitor compliance with the NPDES temperature limits for this outfall includes the use of a numerical model that solves a set of governing equations for the flow and hydrothermal conditions of the SQN release and the river discharge. The numerical model operates in real-time and utilizes a combination of measured and computed values for the temperature, flow, and stage in the river; and the temperature and flow from the SQN discharge diffusers. Part III, Section G of the permit states: *The numerical model used to determine compliance with the temperature requirements for Outfall 101 shall be subject of a calibration study once during the permit cycle. The study should be accomplished in time for data to be available for the next permit application for re-issuance of the permit. A report of the study will be presented to the division of Water Pollution Control.* This report is provided in fulfillment of these requirements.

The basic formulation of the numerical model is presented herein. Three empirical terms are used to calibrate the model. The first is the effective width of the diffuser slot and the second is a relationship used to compute the entrainment of ambient water along the trajectory of the plume. These two items were included in a calibration study performed in 2003 in support of the current NPDES permit (TVA, 2003). The third term, new in the updated calibration study summarized herein, is a relationship for the amount of diffuser effluent that is re-entrained into the diffuser plume for sustained low river flow. The need for this re-entrainment function was discovered as a result of the current drought in East Tennessee. Recent studies have provided evidence that such re-entrainment occurs due to the local buildup of heat in the river that occurs for low flows (TVA, 2009).

Temperature measurements across the downstream end of the SQN mixing zone from forty-nine sets of samples collected between 1982 and 2007 were used in the updated calibration study. These data were compared with computed downstream temperatures from the numerical model for the same periods of time. In this process, sensitivity tests were performed for the effective diffuser slot width, entrainment relationship, and plume re-entrainment function. The results showed acceptable agreement between computed and measured temperatures, particularly at river temperatures greater than 75°F. In the updated study, the overall average discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy improved to about 0.38 F° (0.21 C°). Compared to the previous model calibration this represents an overall improvement of 0.13 F° (0.07 C°), and for downstream temperatures above 75°F an improvement of 0.02 F° (0.01 C°).

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INTRODUCTION

The Sequoyah Nuclear Plant (SQN) is located on the right bank of Chickamauga Reservoir at Tennessee River Mile (TRM) 484.5. As shown in Figure 1, the plant is northeast of Chattanooga, Tennessee, about 13.5 miles upstream and 45.4 miles downstream of Chickamauga Dam and Watts Bar Dam, respectively. As shown in Figure 2, the reservoir in the vicinity of SQN contains a deep main channel with adjacent overbanks and embayments. The main channel is approximately 900 feet wide and 50 to 60 feet deep, depending on the pool elevation. The overbanks are highly irregular and usually less than 20 feet deep.

SQN has two units with a total net generating capacity of 2440 MWe and an associated waste heat load of about 4800 MWe, or 16.4 x 10^9 Btu/hr. The heat transferred from the steam condensers to the cooling water is dissipated to the atmosphere by two natural draft cooling towers, to the river by a two-leg submerged multiport diffuser, or by a combination of both. The release to the river is identified in the National Pollutant Discharge Elimination System (NPDES) Permit as Outfall 101.

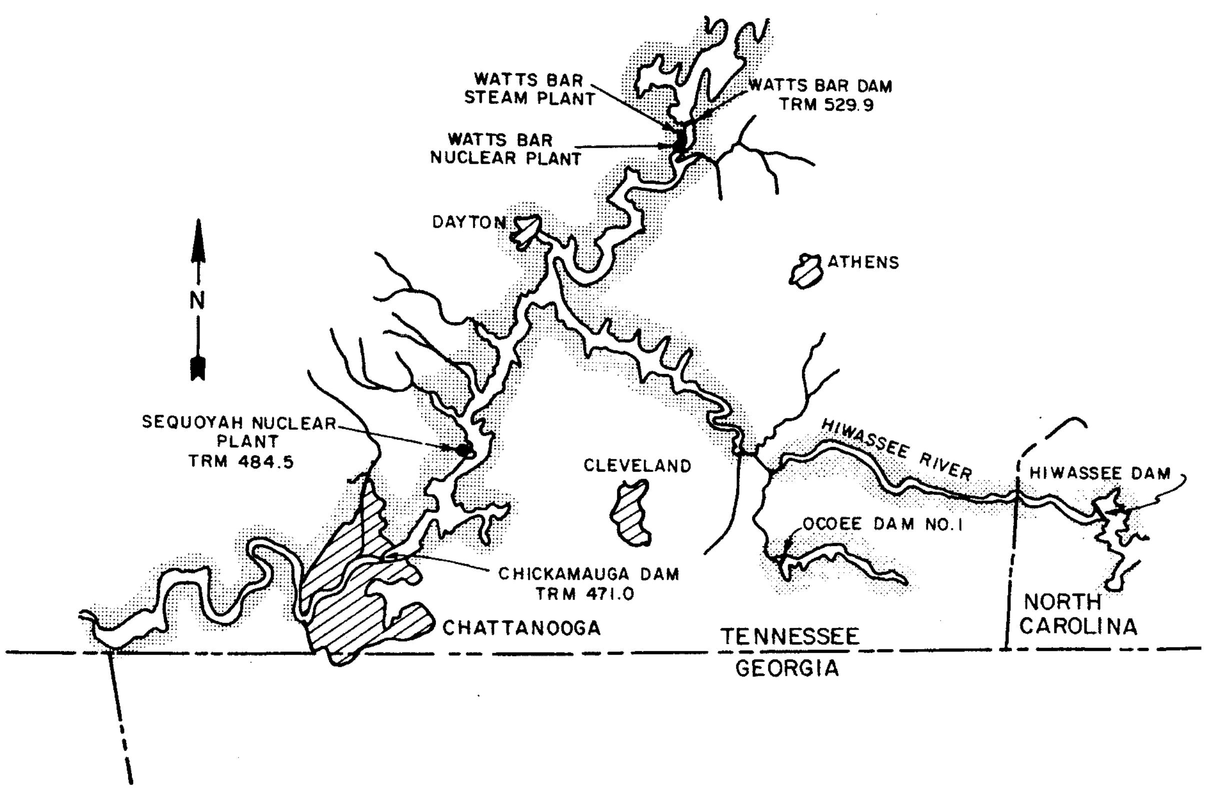

Figure 1. Location of Sequoyah Nuclear Plant

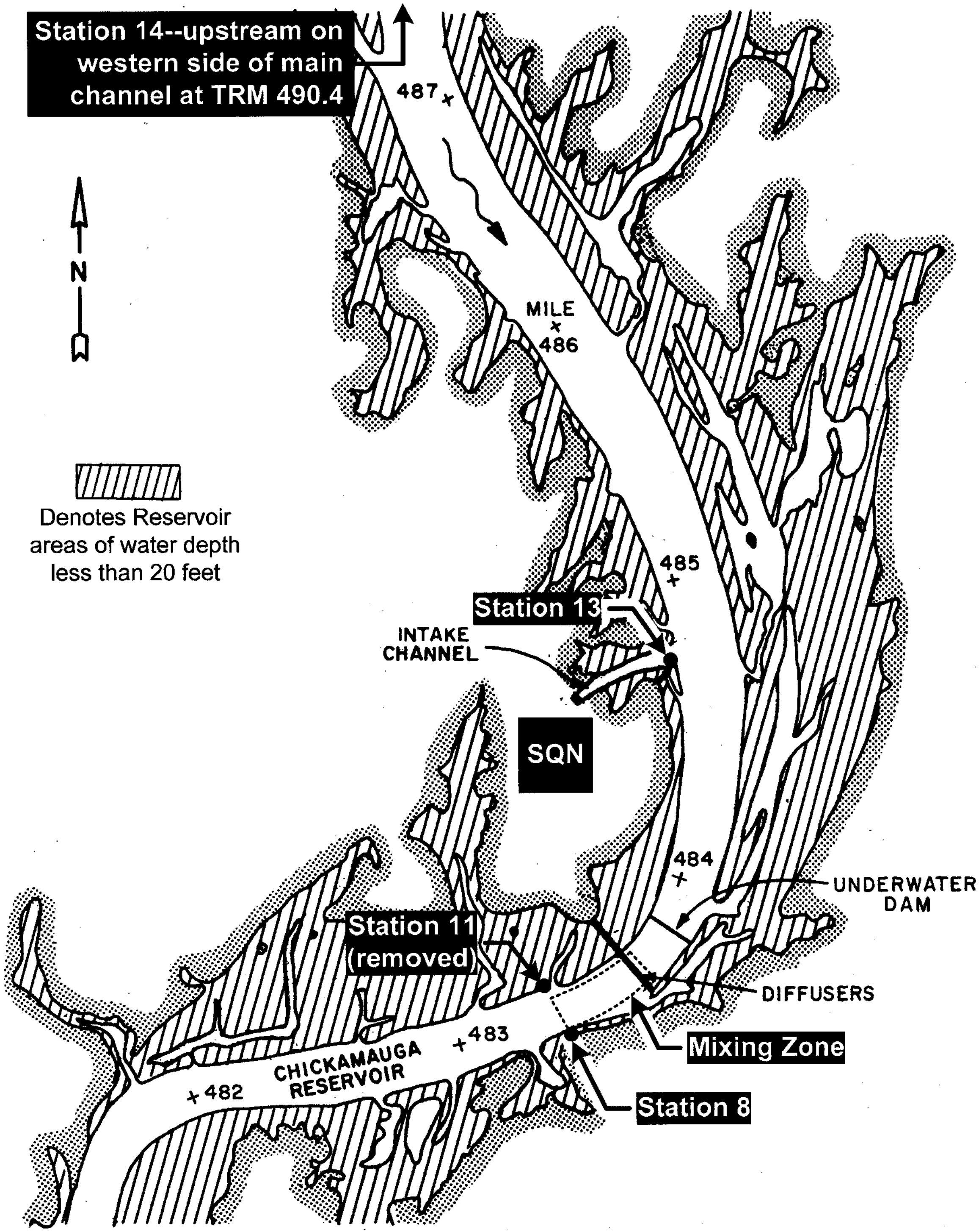

Figure 2. Chickamauga Reservoir in the Vicinity of Sequoyah Nuclear Plant

The compliance of SQN operation with the instream temperature limits specified in the NPDES permit (TDEC, 2005) is based on a downstream temperature that is calculated on a real-time basis by a numerical computer model. Part III, Section G of the permit states:

> *The numerical model used to determine compliance with the temperature requirements for Outfall 101 shall be subject of a calibration study once during the permit cycle. The study should be accomplished in time for data to be available for the next permit application for re-issuance of the permit. A report of the study will be presented to the division of Water Pollution Control. Any adjustments to the numerical model to improve its accuracy will not need separate approval from the Division of Water Pollution Control; however, the Division will be notified when such adjustments are made.*

This report presents a summary of compliance model and the required calibration study.

BACKGROUND

The original method of monitoring thermal compliance for the SQN diffuser discharge (i.e., Outfall 101), included two temperature stations located near the downstream corners of the mixing zone, Station 8 and Station 11 (see Figure 2). Because of the necessity to keep the navigation channel free of obstructions, temperature stations could not be situated between these locations to monitor the center of the thermal plume. The upstream ambient river temperature was measured at Station 13, located on the plant intake skimmer wall. In August 1983, the Tennessee Valley Authority (TVA) reported the results of six field studies of the SQN diffuser performance under various river and plant operating conditions (TVA, 1983a). The data summarized in the report showed that based on measured temperature variations across the downstream edge of the mixing zone, Station 8 and Station 11 were inadequate in providing a representative cross-sectional average temperature of the thermal plume. In particular, it was found that Station 11 was often not in the main flow path of the thermal plume and did not always show elevated temperatures. The remaining downstream monitor, Station 8, also was not considered adequate because it again was located outside the navigation channel. In the report, TVA proposed an alternate method to monitor thermal compliance involving the use of a numerical model to simulate the behavior of the thermal plume in the mixing zone. The model would provide a real-time assessment of compliance with the thermal discharge limitations. Information required for the model included the ambient temperature upstream of the mixing zone (Station 13), the temperature and discharge of the water issuing from the diffusers (Station 12), and the depth and discharge of the river at SQN (determined from measurements at Chickamauga Dam and Watts Bar Dam). A microcomputer, located in the SQN Environmental Data Station (EDS), was to be used collect the required data, compute the thermal compliance parameters, and distribute the results to plant operartors (see TVA, 1983b). The August 1983 report presented results demonstrating the validity of using the numerical model for tracking compliance with the Outfall 101 thermal limitations.

The method of using the numerical model was sent to the Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC), requesting approval for implementation as a valid means for monitoring SQN thermal compliance. The key advantage of the method includes a representation of the cross-sectional average downstream temperature that is at least as good as the instream temperature measurements from Station 8 and Station 11. The method also provides consistency with procedures that are used for scheduling releases from Watts Bar Dam and Chickamauga Dam, as well as procedures for operating Sequoyah Nuclear Plant. This consistency helps TVA minimize unexpected events that can potentially threaten the NPDES thermal limits for Outfall 101. In March 1984 approval was granted for TVA to use the numerical model as the primary method to track thermal compliance. Except for infrequent outages, the model has been in use ever since. Subsequently, Station 11 was removed from the river. However, Station 8 was retained to provide an optional method to track thermal compliance should there be a need to remove the model from service.

Due to the ever changing understanding of the hydrothermal aspects of Chickamauga Reservoir, as well as the operational aspects of the nuclear plant and river system, modifications have been necessary over the years for both the numerical model and thermal criteria for Outfall 101. The current version of the model is presented in more detail later. The current thermal criteria are presented in Table 1. The limit for the temperature at the downstream end of the mixing zone (T_d) is a 24-hour average value of 86.9°F (30.5°C) and an hourly average value of 93.0°F (33.9°C). The instream temperature rise (ΔT) is limited to a 24-hour average of 5.4 F° (3.0 C°) for months April through October, and 9.0 F° (5.0 C°) for months November through March. The latter "wintertime" limit was obtained by a 316(a) variance. The temperature rate-of-change at the downstream end of the mixing zone (dT_d/dt) is limited to ±3.6 F°/hr (±2 C°/hr). With the compliance model, dT_d/dt is based on 24-hour average river conditions and 15 minute plant conditions. Other details related to the temperature limits for Outfall 101 are provided in the notes that accompany Table 1. It is important to note that compliance with instream temperature limits are based on a computed downstream temperature at a depth of 5.0 feet. And in a similar fashion, the upstream temperature is measured at the 5.0 foot depth, based on the average of temperature readings at the 3-foot, 5-foot and 7-foor depths.

Originally, the ambient river temperature for the temperature rise was measured at Station 13, about 1.1 miles upstream of the discharge diffusers. At the onset of the current drought it was discovered that under sustained low flow conditions, heat from the diffusers could migrate far enough upstream to reach Station 13. In this manner, the ambient temperature can become elevated, thereby artificially reducing the measured impact of the plant on the river (i.e., ΔT). As such, in late March 2006, a new ambient temperature station was installed further upstream in the river at TRM 490.4, about 6.8 miles upstream of the diffusers. The location of the new monitor, entitled Station 14, is shown in Figure 3.

Table 1. Summary of SQN Instream Thermal Limits for Outfall 101

Type of Limit	Averaging (hours)	NPDES Limit[2]
Max Downstream Temperature, T_d	24	86.9°F (30.5°C)
Max Downstream Temperature, T_d	1	93.0°F (33.9°C)
Max Temperature Rise, ΔT	24	5.4 F°/9.0 F° (3.0 C°/5.0 C°)
Max Temperature Rate-of-Change, dT_d/dt	Mixed	±3.6 F°/hr (±2 C°/hr)

Notes:

1. Compliance with the river limitations (river temperature, temperature rise, and rate of temperature change) shall be monitored by means of a numerical model that solves the thermohydrodynamic equations governing the flow and thermal conditions in the reservoir. This numerical model will utilize measured values of the upstream temperature profile and river stage; flow, temperature and performance characteristics of the diffuser discharge; and river flow as determined from releases at the Watts Bar and Chickamauga Dams. In the event that the modeling system described here is out of service, an alternate method will be employed to measure water temperatures at least one time per day and verify compliance of the maximum river temperature and maximum temperature rise. Depth average measurements can be taken at a downstream backup temperature monitor at the downstream end of the diffuser mixing zone (left bank Tennessee River mile 483.4) or by grab sampling from boats. Boat sampling will include average 5-foot depth measurements (average of 3, 5, and 7-foot depths). Sampling from a boat shall be made outside the skimmer wall (ambient temperature) and at quarter points and mid-channel at downstream Tennessee River mile 483.4 (downstream temperature). The downstream reported value will be a depth (3, 5, and 7-foot) and lateral (quarter points and midpoint) average of the instream measurements. Monitoring in the alternative mode using boat sampling shall not be required when unsafe boating conditions occur.
2. Compliance with river temperature, temperature rise, and rate of temperature change limitations shall be applicable at the edge of a mixing zone which shall not exceed the following dimensions: (1) a maximum length of 1500 feet downstream of the diffusers, (2) a maximum width of 750 feet, and (3) a maximum length of 275 feet upstream of the diffusers. The depth of the mixing zone measured from the surface varies linearly from the surface 275 feet upstream of the diffusers to the top of the diffuser pipes and extends to the bottom downstream of the diffusers. When the plant is operated in closed mode, the mixing zone shall also include the area of the intake forebay.
3. Information required by the numerical model and evaluations for the river temperature, temperature rise, and rate of temperature change shall be made every 15 minutes. The ambient temperature shall be determined at the 5-foot depth as the average of measurements at depths 3 feet, 5 feet, and 7 feet. The river temperature at the downstream end of the mixing zone shall be determined as that computed by the numerical model at a depth of 5 feet.
4. Daily maximum temperatures for the ambient temperature, the river temperature at the downstream edge of the mixing zone, and temperature rise shall be determined from 24-hour average values. The 24-hour average values shall be calculated every 15 minutes using the current and previous ninety-six 15-minute values, thus creating a 'rolling' average. The maximum of the ninety-six observations generated per day by this procedure shall be reported as the daily maximum value. For the river temperature at the downstream end of the mixing zone, the 1-hour average shall also be determined. The 1-hour average values shall be calculated every 15 minutes using the average of the current and previous four 15-minute values, again creating a rolling average.
5. The daily maximum 24-hour average river temperature is limited to 30.5°C. Since the state's criteria makes exception for exceeding the value as a result of natural conditions, where the 24-hour average ambient temperature exceeds 29.4°C and the plant is operated in helper mode (full operation of one cooling tower, at least three lift pumps, per operating unit) the maximum temperature may exceed 30.5°C. In no case shall the plant discharge cause the 1-hour average downstream river temperature at the downstream of the mixing zone to exceed 33.9°C without the consent of the permitting authority.
6. The temperature rise is the difference between the 24-hour average ambient river temperature and the 24-hour average temperature at the downstream end of the mixing zone. The 24-hour average temperature rise shall be limited to 3.0 C° during the months of April through October. The 24-hour average temperature rise shall be limited to 5.0 C° during the months of November through March.
7. The rate of temperature change shall be computed at 15-minute intervals based on the current 24-hour average ambient river temperature, current 24-hour-hour average river flow, and current values of flow, and current 15-minute values of flow and temperature of water discharging through the diffuser pipes. The 1-hour average rate of temperature change shall be calculated every 15-minutes by averaging the current and previous four 15-minute values. The 1-hour average rate of temperature change shall be limited to 2 C° per hour.

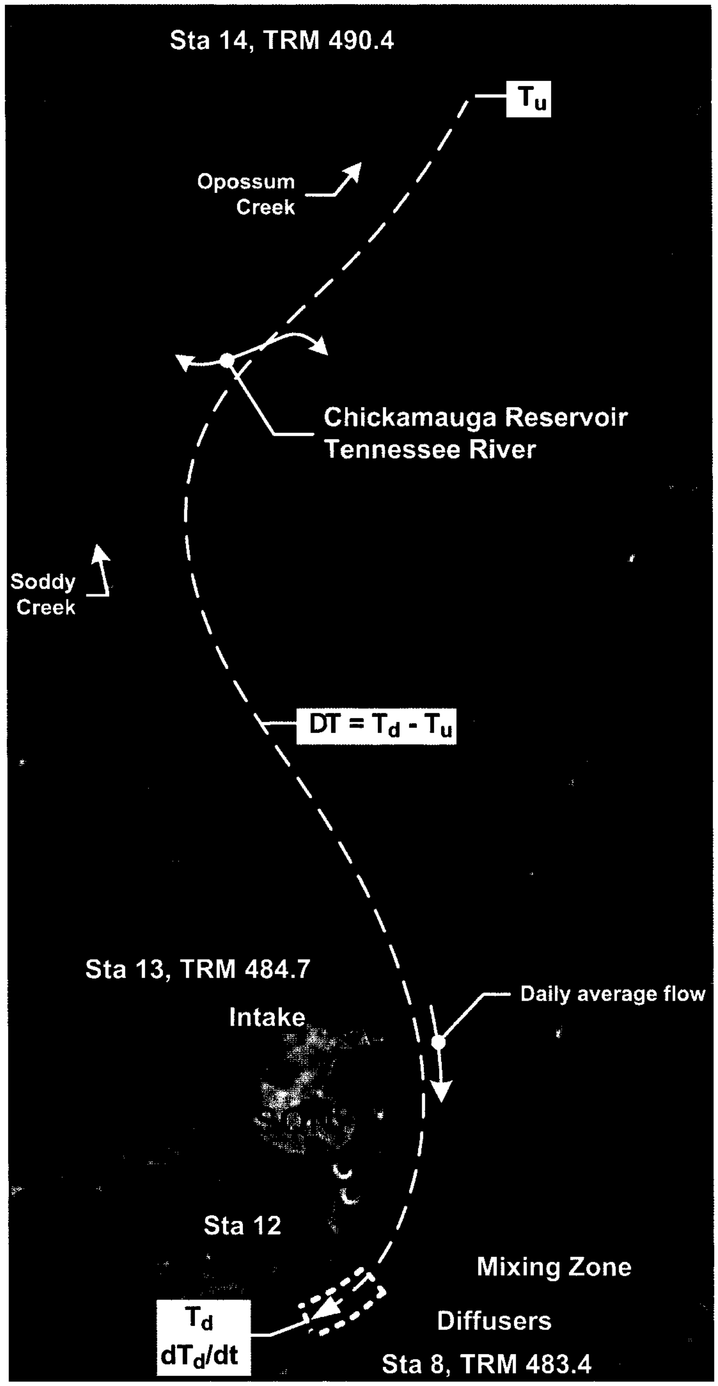

Figure 3. Locations of Instream Temperature Monitors for Sequoyah Nuclear Plant

NUMERICAL MODEL

The diffusers at SQN are submerged at the bottom of the navigation channel in Chickamauga Reservoir. As shown in Figure 4, each diffuser is 350 feet long, and contains seventeen 2-inch diameter ports per linear foot of pipe, arranged in rows over an approximately 18 degree arc of the diffuser conduit. The two diffuser legs rest on an elevated pad approximately 10 feet above the bottom of the river, occupying the 700 feet of navigation channel nearest the plant (right side of the channel, looking downstream). The flow in the immediate vicinity of the ports is far too complex to be analyzed on a real-time basis with current computer technology. Therefore, a simplifying assumption is made that the diffusers can be treated as a slot jet with a length equal to that of the perforated sections of the pipe. The width of this assumed slot is one of three empirical terms used to calibrate the model. The second is a relationship used to compute the entrainment of ambient water along the trajectory of the plume and the third is a relationship for the amount of diffuser effluent that is re-entrained into the diffuser plume for sustained low river flow.

The initial development of the numerical model is described in detail by Benton (2003). Prior to the current drought, the model did not include re-entrainment of the plant thermal effluent for sustained low river flows. However, recent studies have provided evidence that re-entrainment occurs (TVA, 2009). To simulate this situation, the numerical model has been modified to better reflect the local buildup of heat that occurs in the river under such conditions. Before presenting calibration results, it is appropriate first to provide a brief description of the model formulation.

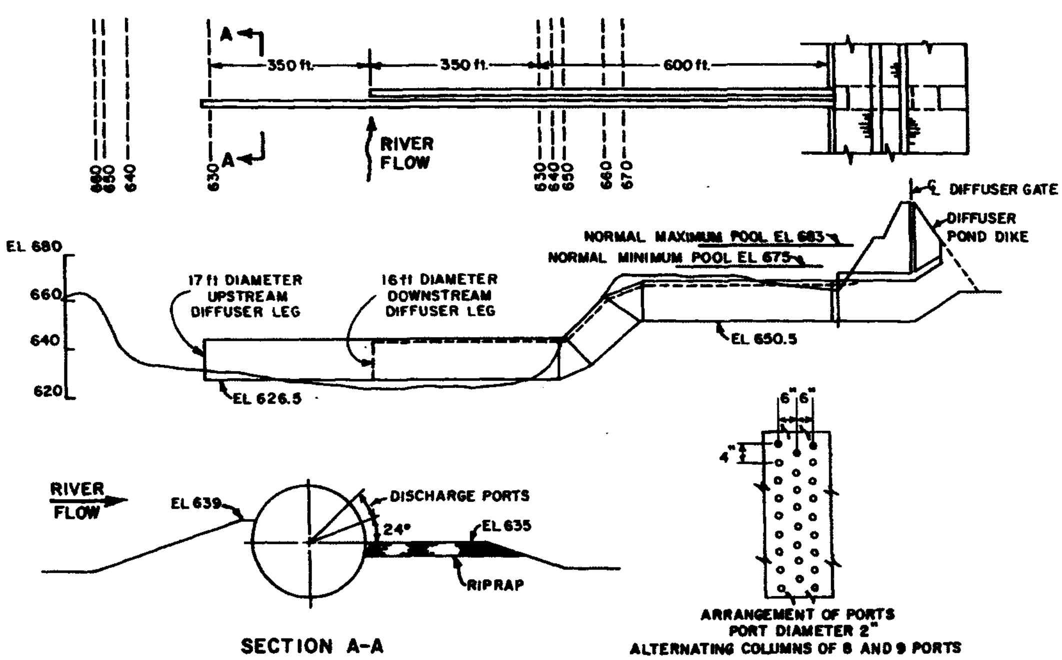

Figure 4. Sequoyah Nuclear Plant Outfall 101 Discharge Diffusers

In general, the model treats the effluent discharge from the diffusers as a fully mixed, plane buoyant jet with a two-dimensional (vertical and longitudinal) trajectory. This is shown schematically in Figure 5. The jet discharges into a temperature-stratified, uniform-velocity flow and entrains ambient fluid as it evolves along its trajectory. The width, *b*, of the jet and the dilution of the effluent heat energy increase along the jet trajectory, decreasing the bulk mixed temperature along its path.

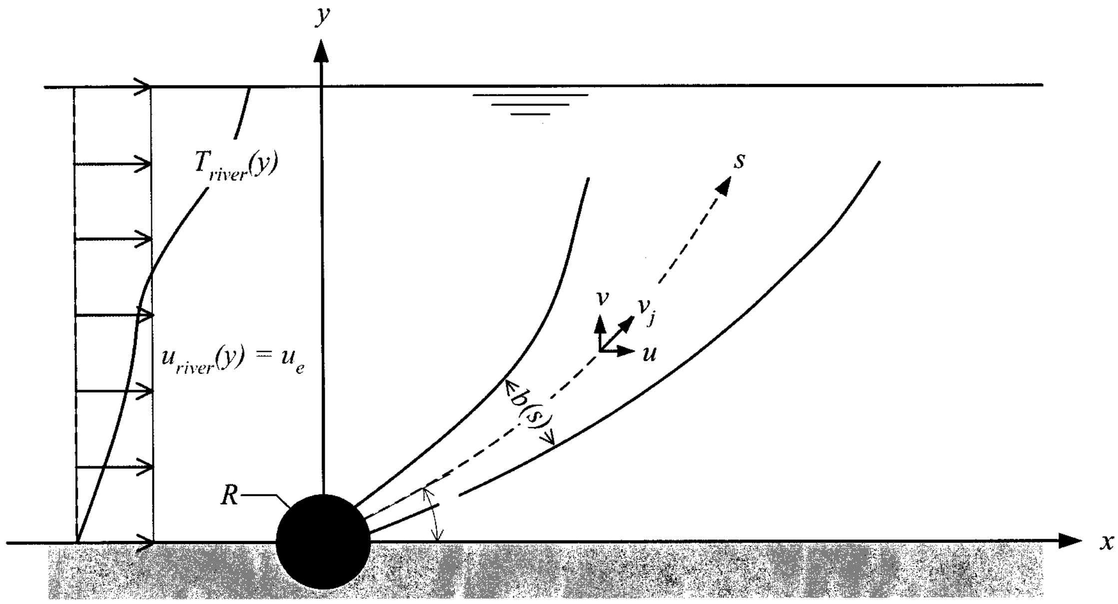

Figure 5. Two-Dimensional Plane Buoyant Jet Model for a Submerged Diffuser

Consideration of the mass, momentum, and energy for a cross section of the plume orthogonal to the jet trajectory and having a differential thickness *ds,* yields the following system of ordinary differential equations,

$$\frac{d}{ds}\left(\rho_j v_j b\right) = m_e \text{ (conservation of mass in jet),} \tag{1}$$

$$\frac{d}{ds}\left(\rho_j v_j b u\right) = m_e u_e \text{ (conservation of x momentum in jet),} \tag{2}$$

$$\frac{d}{ds}\left(\rho_j v_j b v\right) = m_e v_e + bg\left(\rho_e - \rho_j\right) \text{ (conservation of y momentum in jet),} \tag{3}$$

$$\frac{d}{ds}\left(\rho_j v_j b c T_j\right) = m_e c T_e \text{ (conservation of thermal energy in jet),} \tag{4}$$

$$\frac{dx}{ds} = \frac{u}{v_j}\text{, and} \tag{5}$$

$$\frac{dy}{ds} = \frac{v}{v_j}\text{, (velocity of jet tangent to trajectory).} \tag{6}$$

The following auxiliary relationships also are needed to solve the differential equations,

$$m_e = \alpha \rho_e \left[(u_e - u)^2 + v^2 \right]^{1/2}, \tag{7}$$

$$\rho_j = \rho_{water}(T_j), \tag{8}$$

$$\rho_e = \rho_{water}(T_e), \tag{9}$$

$$T_e = T_{river}(y), \tag{10}$$

$$u_e = u_{river}, \tag{12}$$

$$v_e = 0 \text{, and} \tag{13}$$

$$v_j = (u^2 + v^2)^{1/2}. \tag{11}$$

In these equations, the subscripts *j* and *e* denote conditions within the buoyant *jet* and conditions within the water upstream of the mixing zone that is *entrained* by the jet, respectively. Thus, $_j$ denotes the density of water at a point inside the jet and $_e$ denotes the density of water entrained from upstream of the mixing zone. T_e denotes the temperature of the water upstream of the mixing zone that is entrained by the jet. The x-velocity of the entrained water, u_e, is the same as the river velocity, u_{river}, which is negligible in the vertical direction (i.e., $v_e = 0$). The magnitude of the velocity along the jet trajectory is denoted by v_j, with x- and y-components u and v, respectively. The individual jets issuing from the array of 2-inch diameter outlet ports of each diffuser are modeled as a plane jet issuing from a slot of width b_0. Ideally, the slot width is chosen to preserve the total momentum flux issuing from the circular ports of the diffuser. However, as indicated earlier, for this formulation, the slot width is used as a term to calibrate the numerical model. The river velocity u_{river} *is* computed by a one-dimensional unsteady flow model of Chickamauga Reservoir. Apart from information for the reservoir geometry, the basic input for the flow model includes the measured hydro releases at Watts Bar Dam and Chickamauga Hydro Dam and the measured river water surface elevation at SQN.

The transverse gradients of velocity, temperature, and density that occur within the jet due to turbulent diffusion of the effluent momentum and energy are modeled as an entrainment mass flux, m_e, induced by the vectorial difference between the velocity of the jet and that of the river flow upstream of the mixing zone. Empirical relationships for the entrainment coefficient are based on arguments of jet self-similarity and asymptotic behavior. These relationships incorporate non-dimensional parameters, such as a Richardson or densimetric Froude number, that describe the relative strengths of buoyancy and momentum flux in the jet (e.g., see Fischer et al., 1979). Again, as indicated earlier, the entrainment coefficient, like the slot width, is adjusted as part of the calibration process.

The initial conditions required by the model include,

$$b\big|_{s=s_0} = b_0 \,, \tag{14}$$

$$x\big|_{s=s_0} = R\cos\theta \,, \tag{15}$$

$$y\big|_{s=s_0} = R\sin\theta \,, \tag{16}$$

$$u\big|_{s=s_0} = \frac{q_0}{b_0}\cos\theta \,, \tag{17}$$

$$v\big|_{s=s_0} = \frac{q_0}{b_0}\sin\theta \,, \text{ and} \tag{18}$$

$$T_j\big|_{s=s_0} = T_0 \,. \tag{19}$$

This system of differential equations, auxiliary equations, and initial conditions comprise a first-order, initial-value problem that can be integrated from the diffuser slot outlet ($s = s_0$) to any point along the plume trajectory. Note in the above that R is the radius of the diffuser conduit, b_0 is the effective width of the diffuser slot, is the exit angle of the diffuser jet, T_0 is the temperature of effluent issuing from the slot, and q_0 is the effluent discharge per unit length of diffuser. In practice, integration of the governing equations is halted when the jet centerline reaches a point five feet below the water surface (the regulatory compliance depth) or when the upper boundary of the jet reaches the water surface. The jet temperature, T_j, at this point is reported as the fully-mixed temperature to which the thermal regulatory criteria are applied or to which monitoring station data at the edge of the regulatory mixing zone are compared. The integration is done with an adaptive step-size, fourth-order Runge-Kutta algorithm.

In the model, Station 13, located 1.1 miles upstream of the diffusers, is used to represent the temperature of the water entrained in the mixing zone, $T_e = T_{river}(y)$. Whereas this is a good assumption for river flows where the effluent plume is carried downstream, it weakens for low river flows. Based on the understanding gained in recent studies (TVA, 2009), it is known that partial re-entrainment of the effluent plume occurs at sustained low river flow, increasing the temperature of the water entering the mixing zone above that represented by Station 13. To simulate this phenomenon, the model modifies the Station 13 temperature profile for low river flows. For each point in the profile, a local densimetric Froude number is computed as

$$F_r = \frac{u_{river}}{\sqrt{g\left(\frac{\rho_e - \rho_p}{\rho_e}\right)(Z_e - Z_b)}} \,, \tag{20}$$

where u_{river} is the average river velocity, Z_e-Z_b is the elevation of the profile point relative to the bottom elevation of the river, ρ_e is the entrainment water density at that elevation, and ρ_p is the density of the effluent plume at the 5-foot compliance depth. The densimetric Froude number represents the ratio of momentum forces to buoyancy forces in the river flow. If F_r is less than 1.0 (i.e., buoyancy greater than momentum), it is assumed that the buoyancy of the plume is sufficient to cause part of the plume to travel upstream and become re-entrained into the flow, thereby increasing the temperature of the water entering the mixing zone. The modified entrainment temperature T_e^N at each point in the Station 13 profile is computed by repeatedly evaluating

$$T_e^n = R \times T_p + (1.0 - R) \times T_e^{n-1} \tag{21}$$

for values of n from 1 to N, where N is the number of iterations of Eq. (21), R is a re-entrainment fraction, $T_e^{n=0}$ is the original Station 13 temperature, and T_p is the computed plume temperature at the 5-foot depth. N and R are functions of the 24-hour average river velocity. After new Station 13 temperatures have been computed for the entire profile, the mixing zone computation is performed again, using the modified profile to get a new plume temperature at the 5-foot depth. It is emphasized that the final result of the model is the computed temperature at the downstream end of the mixing zone. The instream temperature rise is still computed based on the temperature measurement at the new ambient temperature monitor, Station 14.

Values for N and R are calibrated based on observed temperatures at the downstream end of the diffuser mixing zone for low river flow conditions, as indicated earlier. Depending on the river stage, the modifications by Eq. (21) begin to take effect as the 24-hour average river flow drops through the range of 17,000 cfs to 25,000 cfs, and increases as the 24-hour average river flow continues to drop. For river flows above this range, no modification is needed for re-entrainment.

The downstream temperature and instream temperature rise provided by the model are computed every 15 minutes, using instantaneous values of the measured diffuser discharge temperature (Station 12), measured upstream temperature profile (Station 13), measured ambient temperature (Station 14), measured river elevation (Station 13), and computed values of the river velocity (one-dimensional unsteady flow model of Chickamauga Reservoir) and diffuser discharge. The diffuser discharge is computed based on the difference in water elevation between the SQN diffuser pond (Station 12) and the river (Station 13). All computations are performed every 15 minutes to provide rolling hourly and 24-hour average values. The hourly averages are based on the current and previous four 15-minute values, whereas the 24 hour averages are based on current and previous ninety-six 15-minute values. The temperature rate-of-change is determined slightly different, being computed every 15 minutes based on current 24-hour average river conditions and current 15-minute values of the flow and temperature of water discharging from the SQN diffusers. This method was adopted in August 2001 in order to distinguish between rate-of-change events due to changes in SQN operations (i.e. changes in plant discharge flow and/or temperature) and those due to non-SQN changes in operations (e.g., changes in river flow). Prior to this change, SQN was held accountable for temperature rate-of-change events over which it had very little control or influence.

CALIBRATION

The numerical model is calibrated to achieve the best match between computed downstream temperatures and field measurements at the downstream end of the mixing zone. Field measurements at the downstream end of the mixing zone are of two types—those including samples from field surveys across the entire width of the mixing zone and those from Station 8, which includes samples only at the left-hand corner of the mixing zone (e.g., see Figure 2). Higher priority is given to matching data from field surveys, since such measurements are made across the entire width of the plume mixing zone and are more representative of the average temperature in the thermal plume at the 5-foot compliance depth.

Previous Calibration Data and Calibration Work

Prior to the NPDES permit of September 2005, field surveys were performed in 1981, 1982, 1983, 1987, 1996, 1997, 1999, 2000, 2002, and 2003. In July 1981, TVA conducted the first field survey of the SQN thermal discharge (TVA, 1982). The results of the field surveys were compared to projections from modeling relationships developed from mixing theory and a physical model test of the discharge diffusers. Adequate agreement was achieved between measured data and model projections. In cases where there were discrepancies, the model under-predicted the observed dilutions (i.e., over-predicted temperatures).

Between April 1982 and May 1983, five field surveys containing seventeen sets of samples across the downstream end of the mixing zone were performed to acquire data for validation of the computed compliance technique (TVA, 1983a). The results of these surveys are given in Table 2. Only one SQN unit was operating during the March 1983 test—the other five tests were for operation with two units. The results of the numerical model compared favorably with the field-measured downstream temperatures. On average, the discrepancy between the measured and computed downstream temperatures was about 0.40 F° (0.22 C°). Since the accuracy of the temperature sensors used by TVA are only about ±0.25 F° (±0.14 C°), the agreement between the field measurements and the computer model was considered good. A similar comparison between the Station 8 and Station 11 temperatures and the measured average temperatures across the downstream edge of the mixing zone revealed that the discrepancy for Station 8 was about 0.79 F° (0.44 C°) and for Station 11 about 0.65 F° (0.36 C°). Consequently, it was concluded that the numerical model is not only an accurate representation of the downstream temperature but also is likely superior to the monitoring approach using Station 8 and Station 11.

In September 1987, TVA released a report describing the field surveys in support of the validation and calibration of the SQN numerical model that had been performed up to that date (TVA, 1987). In the report, a chart was introduced that described the ambient and operational conditions for which field surveys had been performed. This chart indicated combinations of river flow, season, and number of operating units, showing what tests had been performed, and assigning relative priorities for tests to be performed in the future. With this guidance, six more field surveys were performed between March 1996 and April 2003, to measure downstream temperatures for various river flows and at different times of year. The results of these surveys produced ten sets of samples across the downstream end of the mixing zone, as given in Table 3.

Table 2. Thermal Surveys at SQN from April 1982 through March 1983

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (F)	T_d Measured (F)	T Measured (F)
04/04/1982	0900 CST	19900	676.46	56.8	61.9	5.1
04/04/1982	1000 CST	19800	676.46	56.7	60.1	3.4
04/04/1982	1100 CST	19600	676.47	56.7	61.2	4.5
04/04/1982	1200 CST	19700	676.50	57.2	61.9	4.7
04/04/1982	1300 CST	19700	676.45	57.4	62.2	4.8
05/14/1982	0900 CDT	7200	682.43	74.5	71.8	-2.7
05/14/1982	1100 CDT	9100	682.40	73.4	71.8	-1.6
05/14/1982	1300 CDT	6300	682.42	72.1	73.6	1.5
09/02/1982	1400 CDT	38500	680.30	78.1	80.1	2.0
11/10/1982	1300 CST	36200	677.57	59.0	60.1	1.1
11/10/1982	1400 CST	31600	677.59	59.0	60.6	1.6
11/10/1982	1500 CST	32300	677.58	59.0	60.4	1.4
03/31/1983	1100 CST	9800	676.34	51.4	54.3	2.9
03/31/1983	1200 CST	9400	676.34	50.4	54.7	4.3
03/31/1983	1300 CST	9300	676.34	52.5	54.5	2.0
03/31/1983	1400 CST	9500	676.34	51.4	54.9	3.5
03/31/1983	1500 CST	9400	676.36	51.4	54.9	3.5

Table 3. Thermal Surveys at SQN from March 1996 through April 2003

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (F)	T_d Measured (F)	T Measured (F)
03/1/1996	1100 CST	42456	676.96	45.9	48.8	2.9
03/1/1996	1445 CST	28136	677.04	46.2	50.2	4.0
03/1/1996	1600 CST	21962	677.00	46.1	51.4	5.3
03/1/1996	1700 CST	20280	677.00	46.0	51.5	5.5
07/24/1997	1550 CDT	40441	682.57	83.5	84.7	1.2
03/24/1999 *	1250 CST	35731	677.46	51.9	54.5	2.7
08/2/2000	1000 CDT	12472	682.20	82.1	85.1	3.0
08/2/2000	1100 CDT	8624	682.20	82.1	85.3	3.1
07/27/2002	1250 CDT	17231	682.37	84.0	86.6	2.6
04/23/2003	1445 CDT	34178	682.53	63.7	64.2	0.5

* The survey of 03/24/1999 is lacking valid upstream temperature data.

Prior to the work summarized herein, the most recent calibration of the numerical model was performed in support of the NPDES permit of September 2005 (TVA, 2003). The results in both Table 2 and Table 3 were used in the model calibration, which includes a total of twenty-seven sets of samples containing temperature measurements across the downstream end of the diffuser mixing zone. In the calibration, the average discrepancy between the measured and computed temperatures at the downstream end of the mixing zone was about 0.68 F° (0.38 C°). For downstream temperatures above 75°F, which is more important in terms of peak summertime stress on aquatic organisms, the average discrepancy was only 0.40 F° (0.22 C°).

New Calibration Data and Calibration Work

Since February 2004 a number of additional field surveys have been performed, providing twenty-three more sets of samples containing temperature measurements across the downstream end of the diffuser mixing for various river flows and at different times of the year. The results of these surveys are given in Table 4. Altogether, therefore, fifty data points with sets of temperature samples across the downstream end of the mixing zone are available for updating the model calibration (i.e., Table 2, Table 3, and Table 4).

Table 4. Thermal Surveys at SQN from February 2004 through November 2007

Date	Approx Time	River		Temperatures (5-foot depth)		
		Flow (cfs)	Stage (ft MSL)	T_u Measured (F)	T_d Measured (F)	T Measured (F)
02/14/2004	0600 CST	51133	677.50	43.7	46.3	2.6
02/22/2004	1800 CST	18468	678.40	45.8	50.5	4.7
08/22/2004	1800 CST	12340	682.00	79.8	84.1	4.3
08/23/2004	1800 CST	39238	682.20	79.8	82.4	2.6
04/01/2006	1915 CST	7084	677.20	59.7	63.5	3.8
04/04/2006	0015 CST	7996	677.70	59.3	63.9	4.6
04/04/2006	1105 CST	8251	677.80	59.6	61.3	1.7
04/04/2006	2030 CST	8258	678.00	59.0	63.2	4.2
04/05/2006	0915 CST	7917	678.20	59.2	62.8	3.6
04/05/2006	2215 CST	8277	678.40	60.4	64.2	3.8
04/06/2006	0915 CST	8174	678.50	59.7	63.3	3.6
04/06/2006	2315 CST	8077	678.70	61.0	64.5	3.5
04/07/2006	0840 CST	8162	678.80	59.9	63.9	4.0
04/07/2006	1435 CST	7889	678.80	60.0	64.7	4.7
05/22/2006	1445 CST	14511	682.00	73.4	72.9	-0.5
05/23/2006	1455 CST	17878	682.20	73.5	73.9	0.4
05/28/2006	1440 CST	13396	682.30	76.6	76.7	0.1
05/29/2006	1435 CST	13713	682.40	77.5	77.6	0.1
05/30/2006	1425 CST	14304	682.40	79.7	79.2	-0.5
09/20/2007	1200 CST	8545	681.80	79.3	83.4	4.1
09/21/2007	1300 CST	8629	681.70	80.6	82.5	1.9
09/22/2007	0600 CST	6969	681.70	79.5	81.8	2.3
11/04/2007	1200 CST	7664	678.70	64.9	69.5	4.6

Diffuser Slot Width

The effective slot width for a multiport diffuser of the type at SQN can be assumed to fall somewhere between the width of a rectangle with length equal to that of the diffuser section and area equal to the total area of the ports; and the width a rectangle with length equal to that of the diffuser section and area equal to the arc length of the perforated section of the diffuser. For the SQN diffuser, this slot width would be between 0.37 feet and 2.67 feet. Five slot widths in this range were evaluated and compared with forty-nine measured data points from the field surveys (i.e., from Table 2, Table 3, and Table 4). The results, given in Figure 6, show that larger slot widths yielded better agreement with the measured data. The nominal arc length of the perforated section of the diffuser (i.e., 2.67 feet) was selected as the best diffuser slot width to be used in the numerical model.

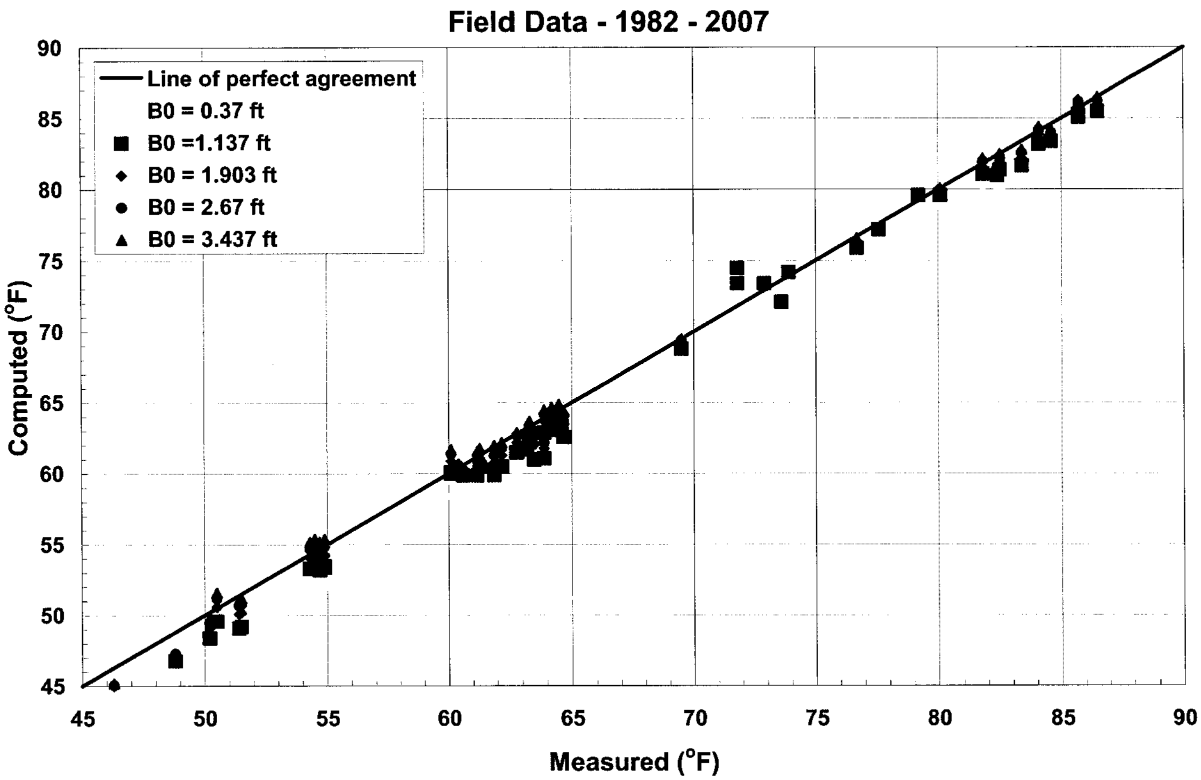

Figure 6. Sensitivity of Computed Temperature T_d to Diffuser Effective Slot Width

Plume Entrainment Coefficient

Two empirical relationships for the plume entrainment coefficient were evaluated in the calibration study. The first, developed by McIntosh, was inferred from a relationship for the entrainment coefficient determined from the data reported in 1983 (TVA, 1983a) and is given by

$$
\alpha = \begin{cases} 0.27 \quad \mathit{for}\ F_d < 0.75 \\ \dfrac{0.27}{F_d^{2.5}} \quad \mathit{for}\ 0.75 \le F_d \le 1.00, \\ 0.55 \quad \mathit{for}\ F_d > 1.00 \end{cases} \tag{22}
$$

where F_d is the densimetric Froude number of the diffuser discharge defined by

$$
F_d = \frac{w_d}{\sqrt{g b_o \dfrac{(\rho_d - \rho_o)}{\rho_o}}}. \tag{23}
$$

The term w_d is the velocity of the diffuser discharge, g is the gravitational constant, b_0 is the diffuser slot width, $_d$ is the density of the diffuser discharge, and $_o$ is the density of the ambient river water at the discharge depth.

The second entrainment coefficient, based on laboratory data, was originally developed by Benton in 1986 and is given by

$$
\alpha = 0.31 + 1.69\left[\frac{1 + tanh(6.543 * rmf - 2.0584)}{2}\right], \tag{24}
$$

where

$$
rmf = u_{river}^{3} / b, \tag{25}
$$

and

$$
b = Q_0\left(\frac{g}{l}\right)\left(\frac{\rho_o - \rho_d}{\rho_o}\right). \tag{26}
$$

Term u_{river} is the ambient river velocity, as previously defined, Q_0 is the diffuser discharge flowrate, and l is the length of the ported section of the diffuser.

Figure 7 shows the comparison with measured data of downstream temperatures computed with the McIntosh (Eq. 22) and Benton (Eq. 24) entrainment coefficients, again based on forty-nine data points from the field surveys in Table 2, Table 3, and Table 4. Both entrainment coefficients result in relatively close matches with the measured data. Although the McIntosh coefficient seems to perform better at low ambient river temperatures, temperatures computed using the Benton coefficient more closely match measured downstream temperatures at higher river temperatures. Since the accuracy of the computation is more critical at temperatures approaching the NPDES limit for downstream temperature, the Benton coefficient, Eq. (24) is currently used in the compliance model.

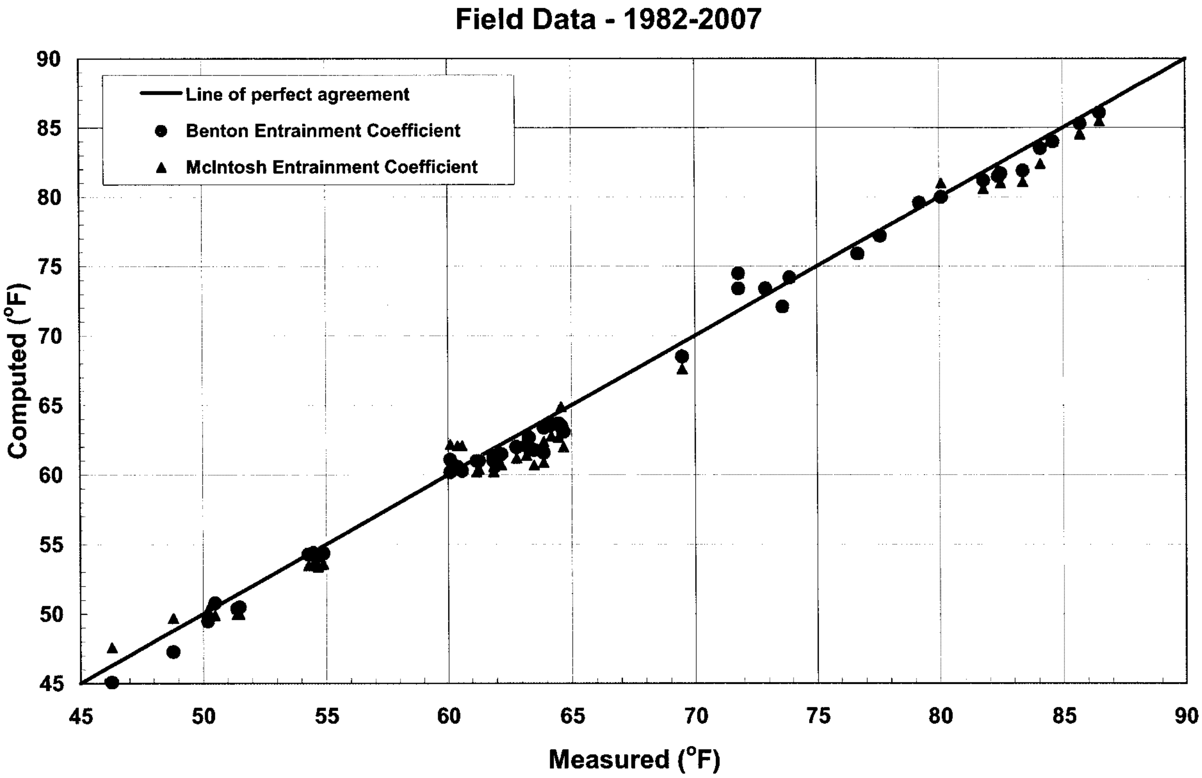

Figure 7. Sensitivity of Computed Temperature T_d to Plume Entrainment Coefficient

Diffuser Effluent Re-Entrainment

Partial re-entrainment of the diffuser plume is known to occur under conditions of low river flow. When the diffuser plume attempts to entrain an amount of ambient flow greater than what is available from further upstream, the upper portions of the plume tend to migrate upstream and plunge downward to be mixed with the flow in the lower portion of the river. The formulation to simulate this phenomenon was presented earlier (Eqs. 20 and 21). The unknown coefficients to be determined in the calibration process are the number of iterations N and re-entrainment fraction R in Eq. (21), which are functions of the 24-hour average river velocity. Based on the evaluation of numerous combinations of N and R, Table 5 gives the values that resulted in computed downstream temperatures that most closely matched measurements in the field surveys (i.e., forty-nine data points from Table 2, Table 3, and Table 4). For river velocities between the values given in Table 5, the re-entrainment factor R is interpolated between the table values. The number of iterations N is interpolated and then rounded to the nearest integer. No re-entrainment correction is performed for 24-hour river velocities greater than the highest value in the table.

Figure 8 shows the comparison of measured and computed downstream temperatures with and without the correction for plume re-entrainment as given in Table 5. Temperatures computed using the plume re-entrainment correction more closely matched measured values for twenty-seven of the forty-nine data points. Temperatures computed without using the plume re-entrainment correction more closely matched measured values for five data points, with no significant differences for the remaining data points. This is considered sufficient improvement to incorporate the plume re-entrainment correction into the computed compliance model.

Table 5. Plume Re-Entrainment Iteration Numbers and Factors

River Velocity (ft/sec)	Number of Iterations *N*	Re-entrainment Factor R
0.000	3	0.21930
0.050	3	0.13300
0.075	3	0.11000
0.100	3	0.10000
0.200	3	0.02670
0.300	3	0.03507
0.400	3	0.00893
0.500	3	0.00447
0.600	0	0.00000

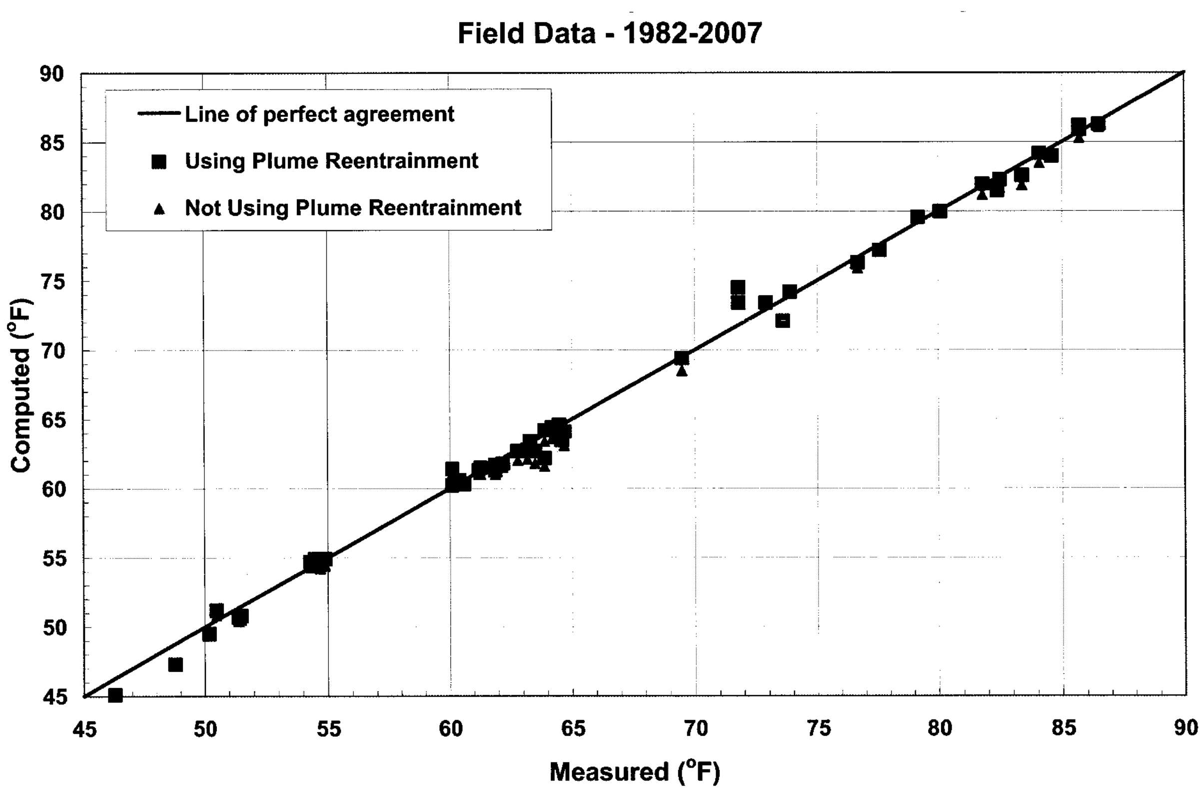

Figure 8. Sensitivity of Computed Temperature T_d to Effluent Re-Entrainment Function

Results of Updated Calibration

For the assumed diffuser slot width and entrainment coefficient, and updated calibration including the re-entrainment function for low river flow, the computed and measured downstream temperatures for the forty-nine downstream temperature data points collected in SQN field surveys since March 1982 are shown in Figure 9. The average discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy improved to about 0.38 F° (0.21 C°). Compared to the previous model calibration performed in 2003 (TVA, 2003) this represents an overall improvement of 0.13 F° (0.07 C°), and for downstream temperatures above 75°F an improvement of 0.02 F° (0.01 C°).

To be consistent with the 24-hour averaging specified in the current NPDES permit, the 24-hour average temperatures measured at the downstream temperature monitor, Station 8, are compared to those computed by numerical model in Figure 10. As before, the measured temperatures correspond to the average of sensor readings at the 3-foot, 5-foot, and 7-foot depths. The figure shows data collected for calendar year 2006, which included a period of exceptional drought in East Tennessee. The overall average discrepancy between the measured and computed 24-hour average downstream temperatures was about 0.51 F° (0.28 C°), and about 0.34 F° (0.19 C°) for downstream temperatures above 75°F. Measured downstream hourly average temperatures for the same time period are compared to those computed by numerical model in Figure 11. The data includes a period in February 2006 when one of the temperature probes temporarily failed, resulting in erroneously low measurements. As expected, the temperature data are much more scattered for the hourly temperatures. The average discrepancy between the measured and computed hourly average downstream temperatures was 0.81 F° (0.45 C°) for the full range of river temperatures, decreasing to 0.54 F° (0.30 C°) for downstream temperatures above 75°F. It needs to be emphasized that in Figure 10 and Figure 11, the data from Station 8 is not necessarily representative of the average temperature across the downstream end of the mixing zone. However, in monitoring the NPDES compliance for Outfall 101, data from Station 8 is considered valuable for verifying basic trends in the downstream temperature as determined by the numerical model, thus providing the motivation for presenting the comparisons given in these figures.

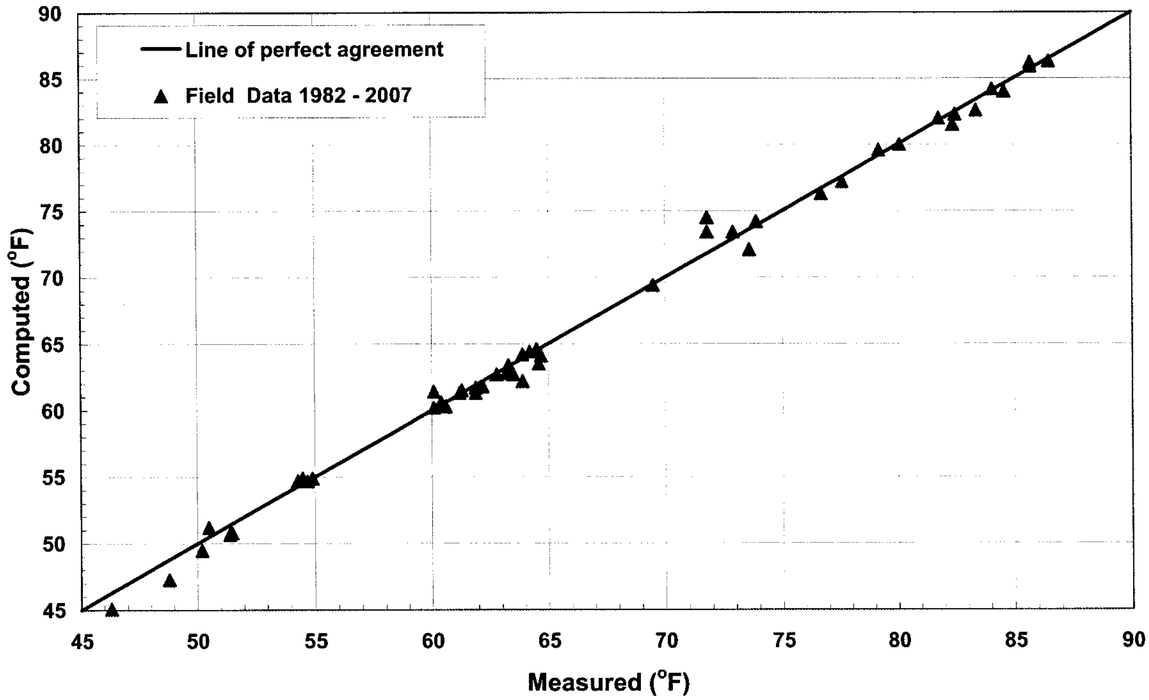

Figure 9. Comparison of Computed and Measured Temperatures T_d for Field Studies from April 1982 through November 2007

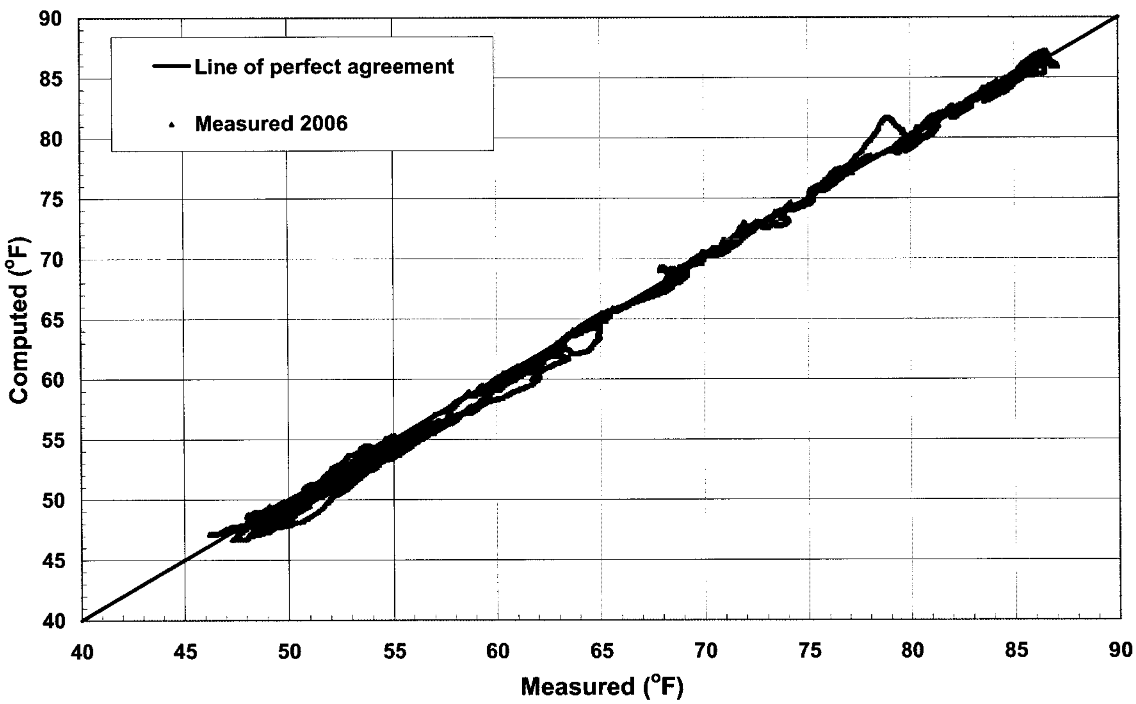

Figure 10. Comparison of Computed and Measured 24-hour Average Temperatures T_d for Station 8 for 2006

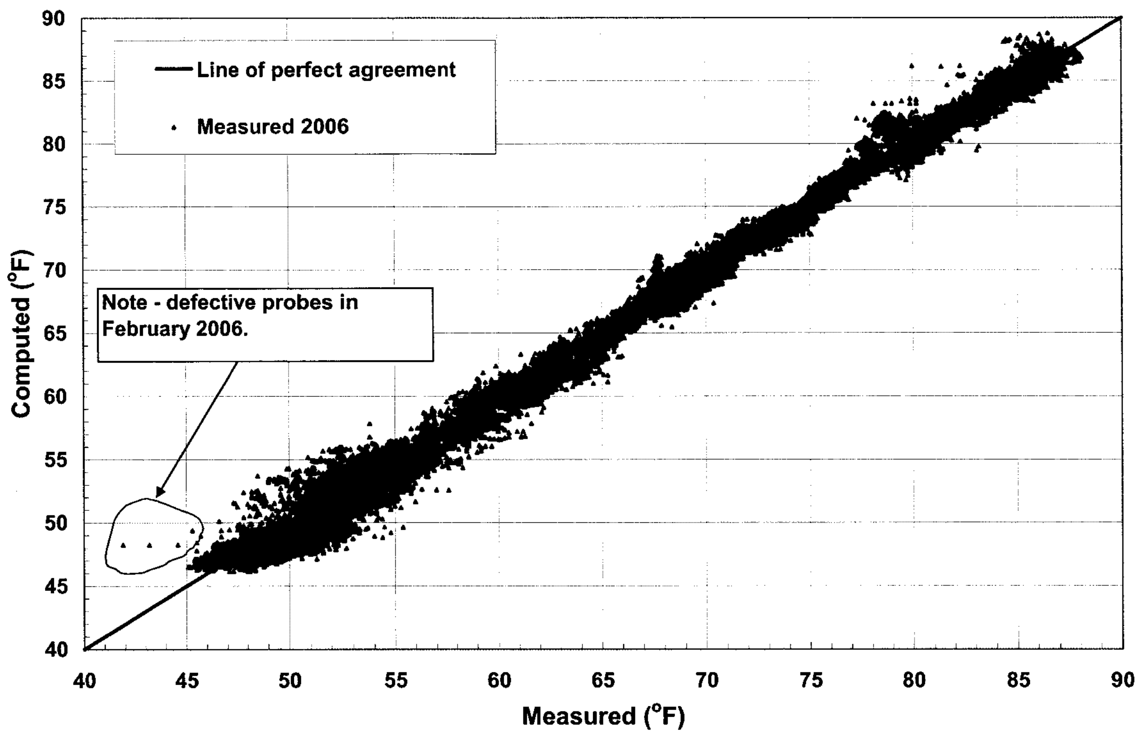

Figure 11. Comparison of Computed and Measured Hourly Average Temperatures T_d for Station 8 for 2006

CONCLUSIONS

The numerical model for the SQN effluent discharge computes the temperature at the downstream end of the mixing zone with sufficient accuracy for use as the primary method of verifying thermal compliance for Outfall 101. Due to observations from the current drought, the numerical model has been modified with a re-entrainment function to better reproduce the local buildup of heat that occurs in the river for sustained low river flow. With this modification, the discrepancy between the measured and computed downstream temperature has improved over that of the previous model calibration that was performed in 2003. Results also show that the model calibration is more accurate at higher river temperatures than at lower temperatures (i.e., above 75°F). This is considered valuable because accuracy is more crucial as the downstream temperatures approach the NPDES temperature limit. In the updated calibration study summarized herein, which used the results from forty-nine sets of temperature samples across the downstream end of the diffuser mixing zone, the average discrepancy between the measured and computed downstream temperatures was about 0.55 F° (0.31 C°). For downstream temperatures above 75°F, the average discrepancy improved to about 0.38 F° (0.21 C°).

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December 9, 2008

Stephanie Howard, SB 2A-SQN

SEQUOYAH NUCLEAR PLANT DIFFUSER DISCHARGE CALIBRATION

As required by NPDES Permit TN0026450 for Sequoyah Nuclear Plant effective September 1, 2005, the calibration has been updated for the discharge through the plant diffusers. Part III, Section G of the permit states that, *"The permittee shall calibrate the flowrate characteristics through the diffusers on a schedule of at least once every two years."* The most recent test was conducted on November 4, 2007. Plant conditions for the test included the operation of three CCW pumps and four ERCW pumps. The test included measurements to determine the flowrate through the diffusers and measurements to determine the diffuser head.

The results of the measurements are given in Attachment 1, which includes a summary of all tests from 1986 through 2007. The rating curve for computing the diffuser flow, given in Attachment 2, has been updated based on the new information. As shown in Attachment 2, the results of all valid tests fall within ±10 percent of the rating curve. This demonstrates that the hydraulic characteristics of the diffusers continue to provide a good method to measure the flow from the plant to the Tennessee River. The updated rating curve was incorporated in the compliance model on November 26, 2007.

It also is noted that the permit states *"For this permit period, such calibration shall be coordinated with the evaluation of the numerical modeling."* To fulfill this requirement, the river temperature at the downstream end of the mixing zone also was measured in the test of November 4, 2007. The results of these measurements will be provided in a separate report summarizing the results of a calibration study of the compliance model, also required by Part II, Section G of the permit.

Paul N. Hopping
Technical Specialist
WT 10B-K

PNH:JGP
Attachments
cc (Attachments):
Boualem Hadjerioua, WT 10B-K
Ann Hurt, SB 2A-SQN
EDMS, WT 10C-K

Attachment 1

Calibration Data for SQN Diffuser Discharge, 1986 – 2007

Test Date	Number Of Pumps		Field Measurements				
			Discharge Measurement Method [(A)]	Water Surface Elevation [(B)]		Diffuser Head H	Diffuser Discharge Q
				Diffuser Pond	River		
	CCW	ERCW		(feet MSL)	(feet MSL)	(feet)	(cfs)
12/18/1986	2	4	MM	678.03	677.00	1.03	889
12/17/1986	3	4	MM	678.46	676.90	1.56	1,297
12/18/1986	4	4	MM	680.41	676.90	3.51	1,686
12/19/1986	6	4	MM	683.53	677.17	6.36	2,490
03/28/1989	5	4	MM	680.80	676.46	4.34	2,015
03/29/1989	5	4	MM	680.82	676.35	4.47	2,161
03/22/1990	2	3	MM	678.44	677.27	1.17	943
04/05/1990	3	4	MM	680.57	678.54	2.03	1,470
10/05/1990	3	4	MM	682.30	680.20	2.10	1,457
12/19/1990	6	4	MM	682.54	676.26	6.28	2,350
04/03/1991	6	4	MM	684.20	678.18	6.02	2,511
05/22/1991	6	4	MM	688.70	682.60	6.10	2,451
12/10/1991	5	4	MM	682.70	677.90	4.80	2,213
04/10/1992	2	3	MM	680.13	679.12	1.01	879
02/18/1994 [(C)]	2	3	MM	679.42	678.13	1.29	871
06/14/1994	6	4	MM	688.50	682.00	6.50	2,507
04/03/1997 [(D)]	3	3	MM	679.50	677.30	2.20	1,223
05/23/1997	6	3	MM	688.40	681.80	6.60	2,551
05/06/1998	6	3	ADCP	688.20	681.70	6.50	2,345
05/11/1999	6	3	ADCP	689.20	682.60	6.60	2,274
10/10/2001	6	3	ADCP	687.10	680.30	6.80	2,359
07/272002	6	4	ADCP	689.40	682.40	7.00	2,759
04/23/2003 [(E)]	3	4	ADCP	684.05	682.20	1.85	1,552
03/07/2006	6	3	ADCP	682.06	675.97	6.09	2,511
11/04/2007	**3**	**4**	**ADCP**	**680.88**	**678.66**	**2.22**	**1,291**

Notes:

(A) MM=Marsh-McBirney instrumentation. ADCP=Acoustic Doppler Current Profiler instrumentation.

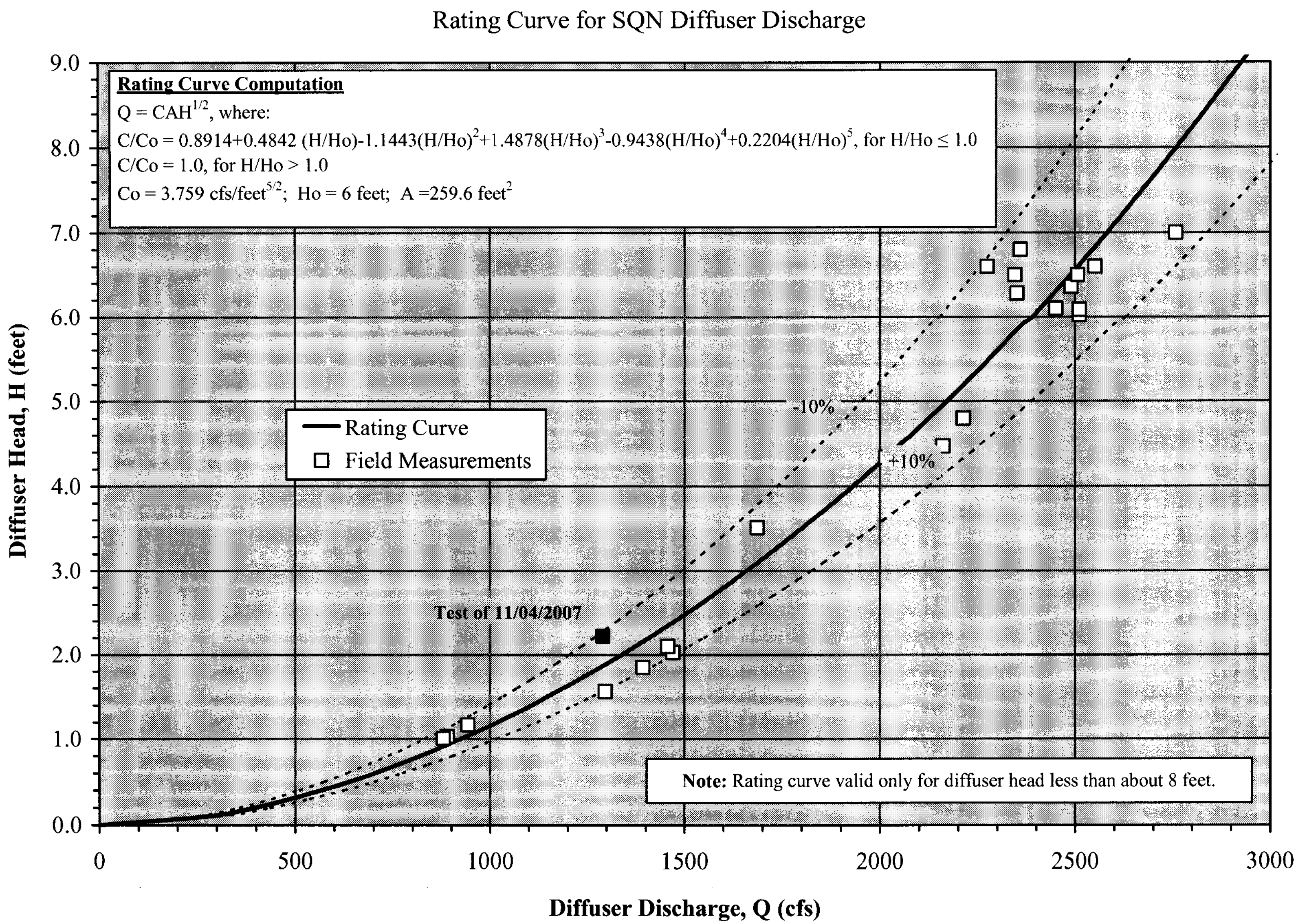
(B) Water surface elevations for the diffuser pond and river recorded by instrumentation of the SQN Environmental Data Station. MSL=Mean Sea Level.

(C) The test of 02/18/94 was performed with very windy conditions, making it difficult to keep the boat steady. Due to the potential error introduced by these conditions, the resulting measurement was not used to determine the head-discharge relationship for the diffuser discharge.

(D) The test of 04/03/97 included a malfunction of the Marsh-McBirney compass, which prohibited the collection of data for flow direction. The diffuser discharge is based on an assumed flow direction. Due to the potential error introduced by these conditions, the resulting measurement was not used to determine the head-discharge relationship for the diffuser discharge.

(E) The test of 04/23/03 was performed with an ADCP setting that likely overestimated the volume of water passing through the diffuser pond. The resulting discharge significantly exceeded the capacity of pumps in service at the time. Due to the potential error introduced by these conditions, the resulting measurement was not used to determine the head-discharge relationship for the diffuser discharge.

Attachment 2



Tennessee Valley Authority, Post Office Box 2000, Soddy-Daisy, Tennessee 37384-2000

February 28, 2006

Dr. Richard Urban
State of Tennessee
Department of Environment and Conservation
Chattanooga Environmental Assistance Center
Division of Water Pollution Control
State Office Building, Suite 550
540 McCallie Avenue
Chattanooga, Tennessee 37402-2013

Dear Dr. Urban:

SEQUOYAH NUCLEAR PLANT (SQN)
DIESEL FUEL OIL INTERCEPTOR SYSTEM: TRIAL CLOSURE

The Diesel Fuel Oil Interceptor System was placed into operation at Sequoyah Nuclear Plant (SQN) in April 1994. The system was designed to intercept diesel fuel oil accidentally released from transfer lines. In accordance with interim monitoring procedures, biweekly monitoring of fuel oil product, groundwater levels, and water quality has been conducted to assure system functionality. Additionally, groundwater discharge from the system to the CCW Channel has been monitored for diesel range organics and extractable petroleum hydrocarbons for compliance purposes.

The attached report summarizes operation and monitoring data at the site from installation through December 2003. Data collected at the site subsequent to December 2003 show negligible differences in field and analytical results. Since May 2000, fuel oil product thickness has been almost immeasurable. Product thicknesses in trench extraction wells (EXT-1 to EXT-3) have shown no measurable product since January 2001. Only two occurrences of measurable product thickness (0.01 ft) have been observed at EXT-4 since January 2001. Groundwater samples of trench effluent (collected biweekly to monthly) indicate decreases in EPH concentrations to detection levels since February 2003. Furthermore, during construction of the Independent Spent Fuel Storage Installation in the 2001/2002 time period, 6300 yd^3 of soil was removed with approval from TDEC Solid Waste Division from an area partially overlapping where the fuel oil leak originally occurred.

The data collected to date and a thorough review of site hydrogeologic characteristics and engineered features at the release location, clearly indicate there is no risk to human health or the environment. Therefore, TVA proposes a trial closure of the diesel interceptor system as described in detail in Section 4 of the attached report. Initially, trial closure shall consist of turning off all pumps while continuing to monitor water/product levels and water quality (EPH) and maintaining visual observations along the CCW channel. The trial closure will extend for a period of two years. Daily inspections (5/week) are conducted of all site impoundments and this will continue through the trial closure period. If visual observations of the CCW Channel indicate fuel oil releases or a product thickness of greater than 0.1 ft are noted in routine monitoring of extraction or monitoring wells, the interceptor system will be immediately returned to operation and water/product level monitoring frequencies will revert to the original schedule.

As indicated in Section 4.3 of the attached report, water quality monitoring shall continue at well EXT-4 upgradient of the interceptor trench, wells 22 and 23 downgradient of the interceptor trench, and the CCW Channel on a quarterly frequency for the 2-year trial closure period. Due to its unique geographical location, there are no downgradient water supply wells located between the SQN site and the Tennessee River. Therefore, we propose the use of wells 22 and 23 for point-of-compliance. If EPH concentrations at either of these wells exceed 10 mg/L EPH, confirmatory sampling will be conducted within two weeks following receipt of analytical results. If subsequent results confirm EPH concentrations greater than 10 mg/L EPH, the interceptor system will be immediately returned to operation and water/product level monitoring frequencies will revert to the original schedule.

At the end of the two-year monitoring period, TVA will submit a report to TDEC documenting results from trial closure and providing recommendations for final closure and well/trench abandonment.

If this proposal meets with your approval, please contact us so that we can initiate trial closure activities. We respectfully request an April 10th concurrence date in order to initiate trial closure during higher precipitation months (worst case scenario).

Sincerely,

Stephanie A. Howard

Stephanie A. Howard
Principal Environmental Engineer
Signatory Authority for
J. Randy Douet
Site Vice President
Sequoyah Nuclear Plant

Tennessee Valley Authority
Energy Research & Technology Applications
Environmental and Engineering Services
Special Projects

SQN INTERCEPTOR SYSTEM
INTERIM MONITORING AND TRIAL CLOSURE

Prepared by
Hank E. Julian, P.E., P.G.

Research & Technology Applications
Knoxville, Tennessee

January 2006

TABLE OF CONTENTS

SQN INTERCEPTOR SYSTEM
INTERIM MONITORING AND TRIAL CLOSURE

1.0 INTRODUCTION

The Diesel Fuel Interceptor System was placed into operation at Sequoyah Nuclear Plant (SQN) in April 1994. The system was designed to intercept diesel fuel oil accidentally released from underground transfer lines. In accordance with interim monitoring procedures, biweekly monitoring of fuel oil product and groundwater levels has been conducted to assure system functionality. Additionally, groundwater discharge from the system to the Condenser Cooling Water (CCW) Channel has been monitored for total petroleum hydrocarbons and diesel range organics for compliance purposes. The purpose of this report is to evaluate data collected at the interceptor trench site since May 1995 and provide recommendations for trial closure and monitoring of the system.

2.0 INTERCEPTOR SYSTEM DESCRIPTION

The fuel oil interceptor system consists of a single interceptor trench containing three (3) 12-inch diameter groundwater/free product extraction wells (EXT-1, 2, and 3). The trench location is shown in Figure 2.1. In addition to the interceptor trench extraction wells, one 8-inch diameter extraction well (EXT-4) has been installed for groundwater/product removal. The system has been designed to operate by maintaining a constant water level within the trench using automated groundwater depression pumps that are coupled to a floating free product removal system.

Groundwater from the depression pumps is discharged to the CCW Channel via underground PVC lines. A valve box exists on the line behind the oil containment building for gathering routine groundwater samples. Oil from the free product pumps is discharged to drums in the oil containment building. Full drum sensors have been installed to prevent accidental overflows.

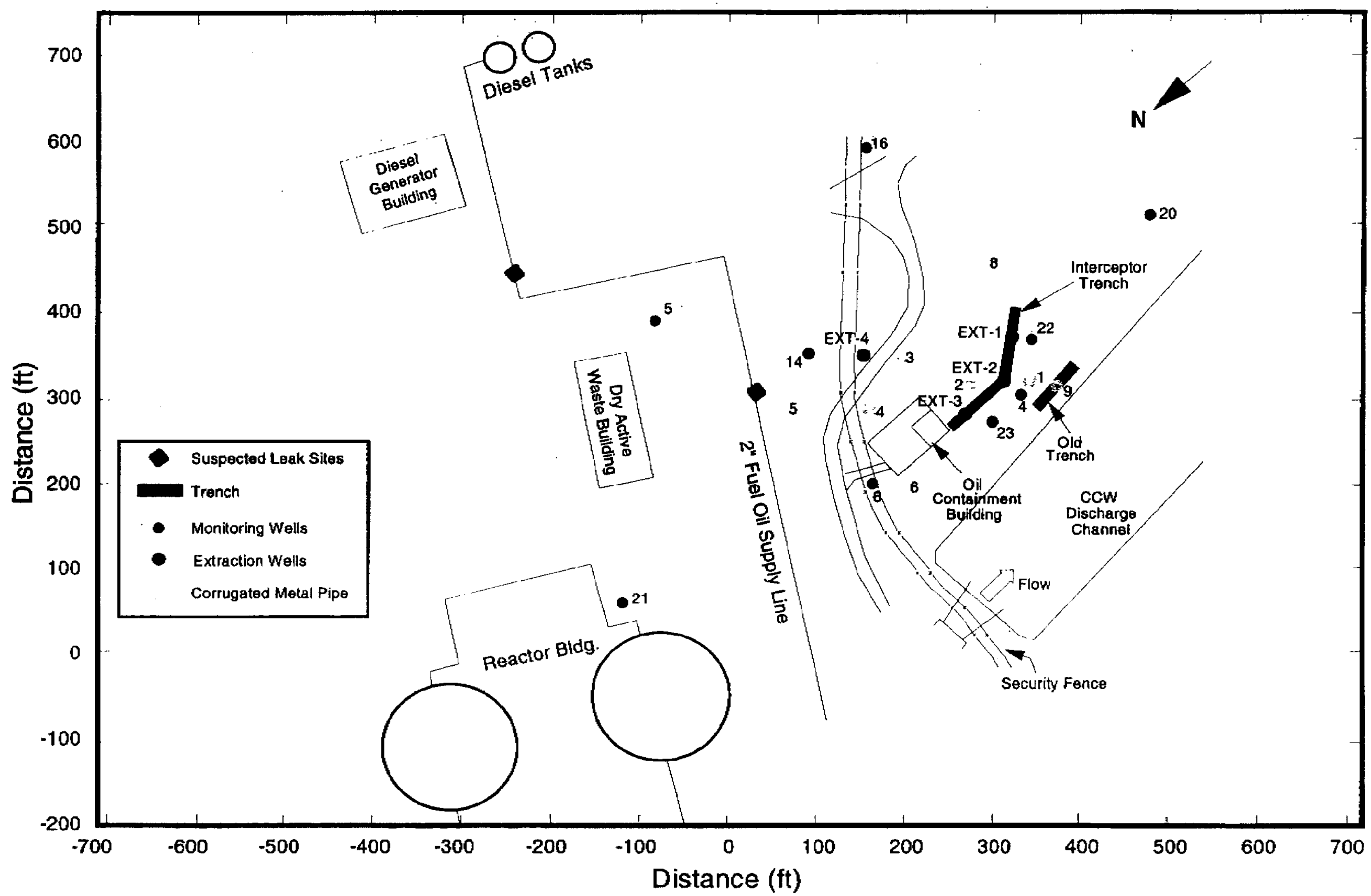
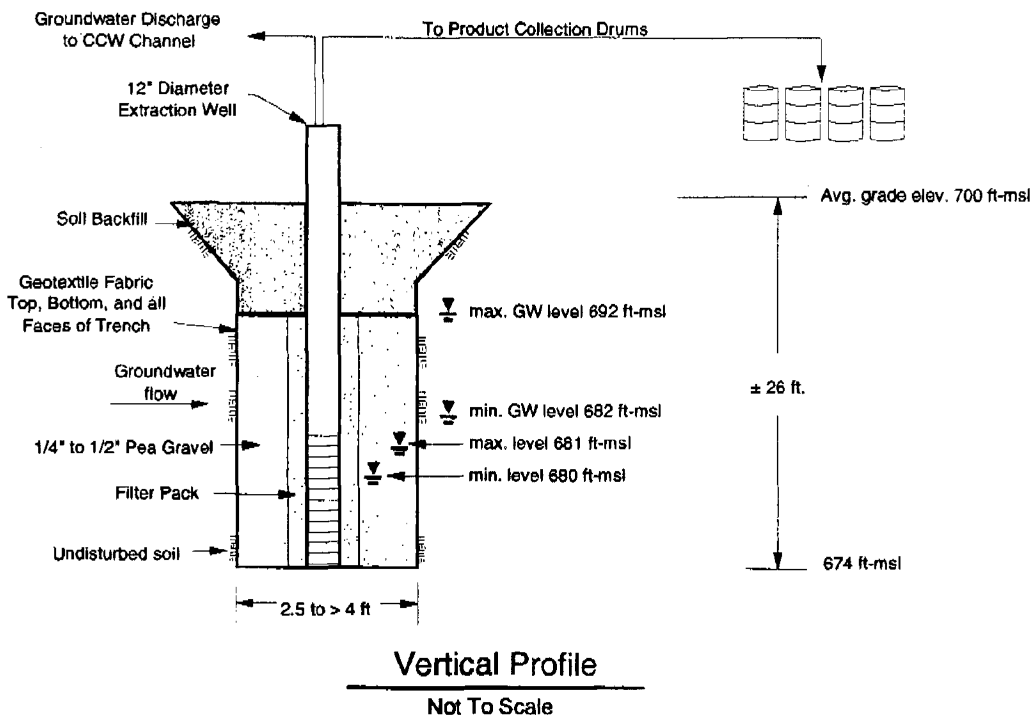


Figure 2.1 Site Map Showing Location of Interceptor Trench



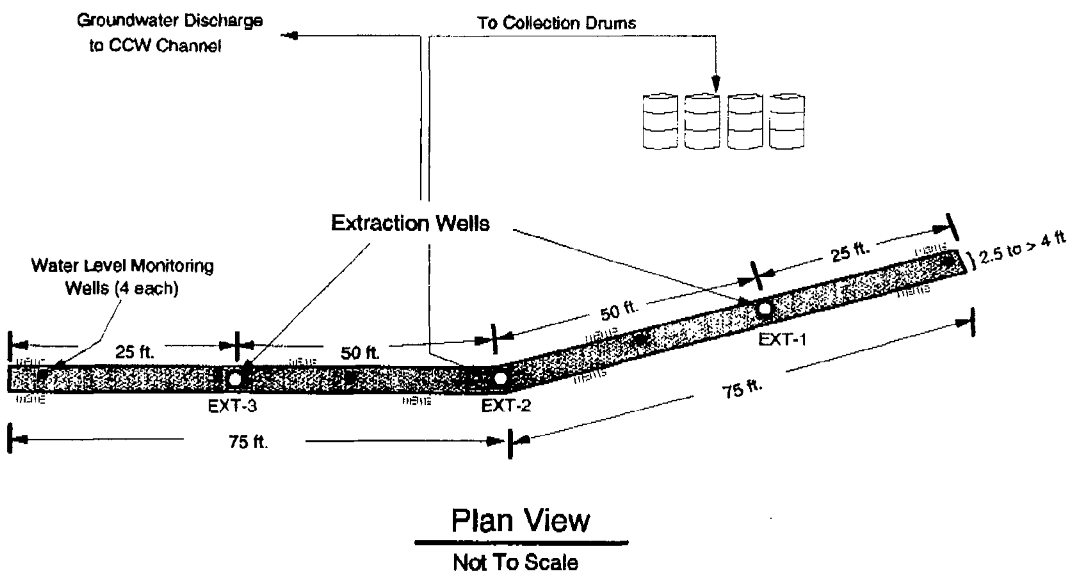


Figure 2.2 Schematic of Interceptor Trench

The interceptor trench was constructed as shown in Figure 2.2, noting that the trench width is variable, but generally increases from bottom to top. After extraction and monitoring well installation, geosynthetic fabric was installed along excavated faces of the trench and pea gravel was used as porous fill. The upper horizon of the trench was capped with natural backfill. Control parameters influencing the trench design were as follows:

1. Groundwater Levels Outside of Trench
   - Anticipated high of 692 ft-msl
   - Anticipated low of 682 ft-msl
2. Controlled Groundwater Level Inside Trench
   - Minimum of 680 ft-msl
   - Maximum of 681 ft-msl
3. Extraction Wells (EXT-1, 2, and 3)
   - 12-inch diameter wire-wrapped stainless steel screen at 0.04-inch slot
   - Screen from 674 to 684 ft-msl
   - Filter Pack is a graded coarse silica sand
4. Monitoring Ports (4 each)
   - 2-inch schedule 40 PVC
   - 0.02-inch machine cut slots
   - Screen from 674 to 695 ft-msl
   - No filter pack required

The location of EXT-4, which was near the centroid of the free product plume originally observed from subsurface investigations at the site, is shown on Figure 2.1. Free-product and groundwater depression pumping equipment is generally the same as that specified for trench. EXT-4 is 8 inches in diameter, continuously-wound schedule-40 PVC, 31 feet deep, screened from 5 feet below ground surface to the bottom of the well, possesses a graded medium-sand filter pack, 2-foot bentonite seal above screen, and is grouted to ground surface above the bentonite seal. The water table depression pump in EXT-4 was originally designed to maintain groundwater levels from 685 to 686 ft-msl but levels were modified in the field.

A description of pumping equipment is as follows:

a. Free Product Removal Pumps

- Electric down-hole product pump (115 VAC, 60 Hz, Single-Phase)
- Water-free oleophilic/hydrophobic screen
- Floating intake with minimum 1-ft travel
- Two sensors inside hydrocarbon reservoir to actuate product and water depression pumps
- Flow rate of 0.25 to 0.5 gpm at 90 feet TDH
- 100 mesh screen
- Explosion proof cast aluminum construction
- Circuit protection
- Drum full sensor to prevent overflows

b. Water Depression Pumps

- Side deployment with free-product pump
- Electric submersible Grundfos pumps
- Flow rate of 1 to 7 gpm
- Actuated by sensors inside hydrocarbon reservoir and water level probe

The oil containment building is located on the old EMB slab and houses four drums for collecting free-product. The discharge lines from the product pumps have been installed in a manifold assembly for flexibility of operation. It is possible to fill one or two drums at a time with the apparatus and have two drums reside as spares for changeover. Two magnetic overflow prevention sensors that fit the bungholes of the drums have been installed to prevent accidental overflows. The sensors are interfaced with the controls to turn off product pump(s) when a drum nears the full level.

3.0 INTERIM OPERATION AND MONITORING RESULTS

3.1 Water Levels and Product Thickness

3.1.1 Extraction Wells

Figure 3.1 shows the results of biweekly monitoring of groundwater levels in extraction wells EXT-1 through EXT-4. As shown, groundwater levels in EXT-1 through EXT-3 are identical with few exceptions. EXT-4 resides upgradient of the interceptor trench where groundwater levels are higher. Prior to May 1996, groundwater levels within the interceptor trench were relatively high. However, since that time groundwater levels have generally been maintained within operational levels of 680 to 683 ft-msl except during brief outages. Groundwater levels at EXT-4 are more variable. The occasional spikes observed in groundwater levels are primarily increases, possibly from recharge by precipitation. Groundwater level increases also occur when the depression pumps are turned off for maintenance or due to control panel problems from power surges (e.g. lightning). There are no correlations in groundwater levels of extraction wells and surface water elevations.

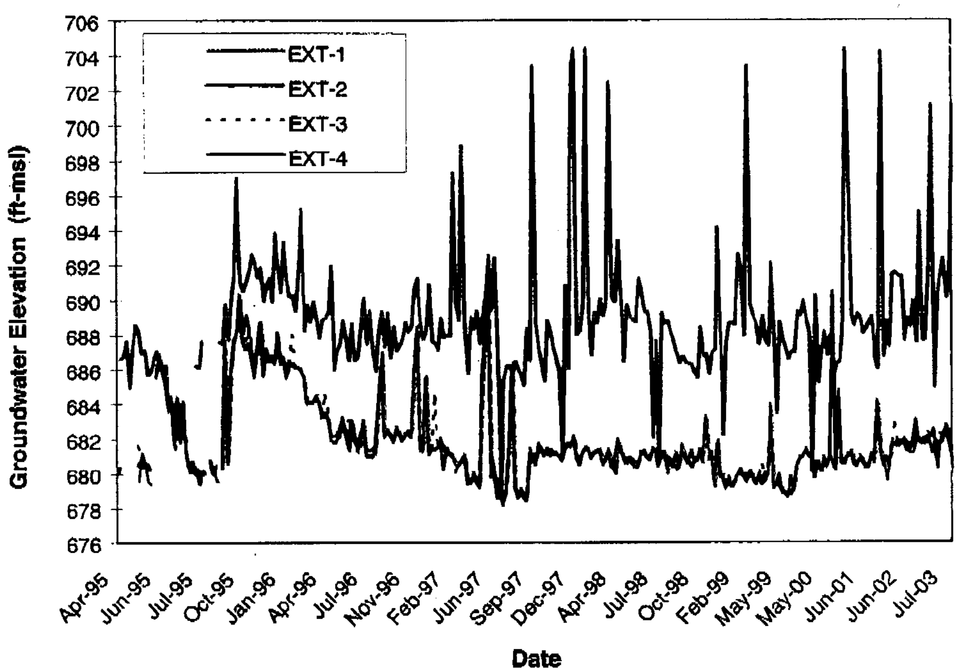


Figure 3.1 Groundwater Levels at Extraction Wells

Figures 3.2 through 3.5 show groundwater levels and product thickness at extraction wells with time. Collectively, the product thickness measurements suggest that fuel oil product has been removed from the subsurface episodically since the interceptor system went online. The current data also indicate declining levels of product at the locations of all extraction wells (Figure 3.6) with product from EXT-4 accounting for the vast majority of accumulated fuel oil. Since May 2000, product thickness has been almost immeasurable. Product thickness in trench extraction wells (EXT-1 to EXT-3) has shown no measurable product since January 2001. Only two occurrences of measurable product thickness (0.01 ft) have been observed at EXT-4 since January 2001.

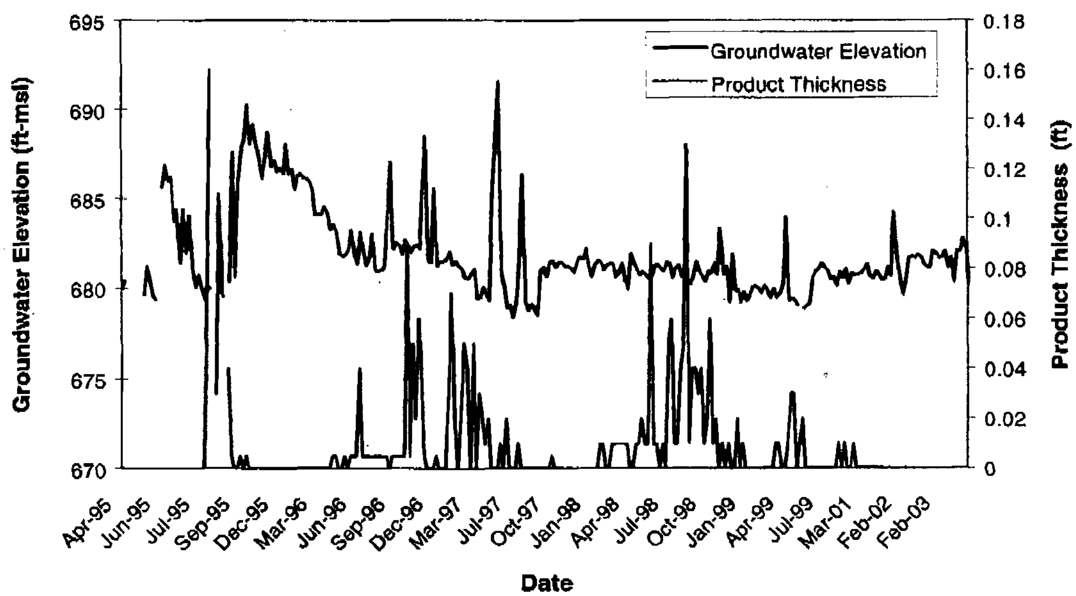


Figure 3.2 Groundwater Elevation and Product Thickness at Extraction Well 1

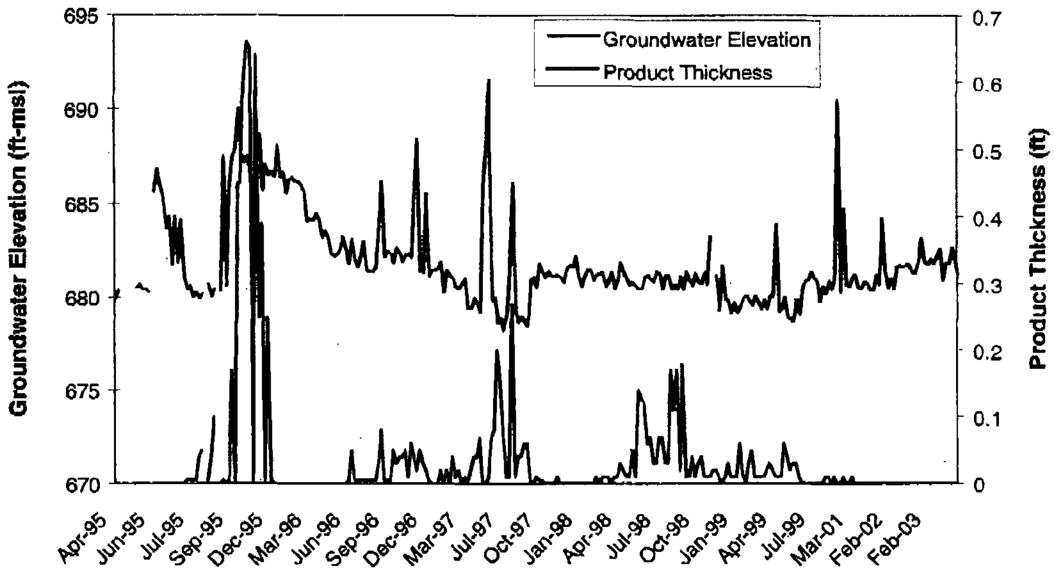


Figure 3.3 Groundwater Elevation and Product Thickness at Extraction Well 2

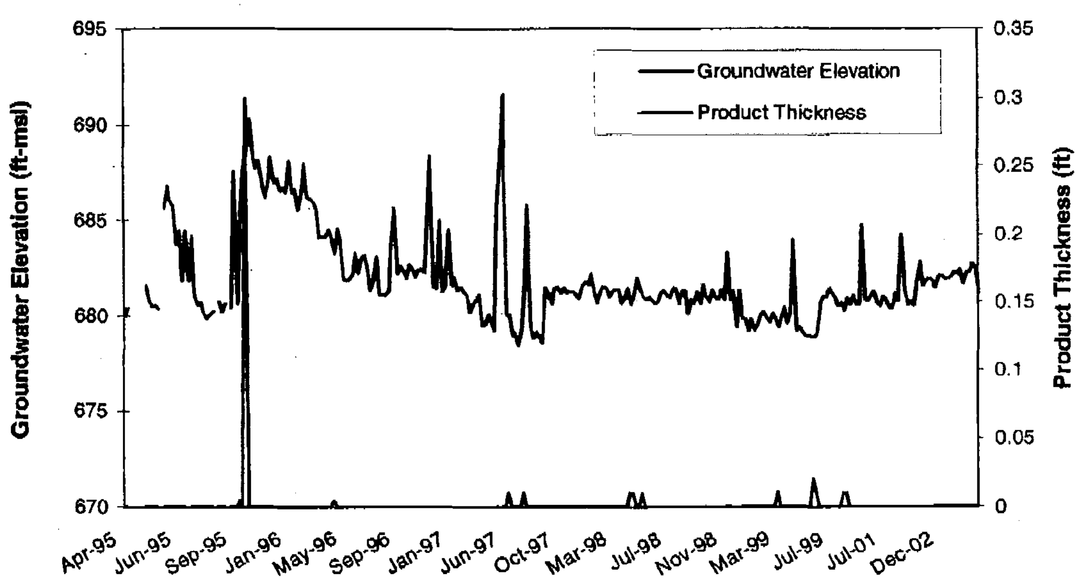


Figure 3.4 Groundwater Elevation and Product Thickness at Extraction Well 3

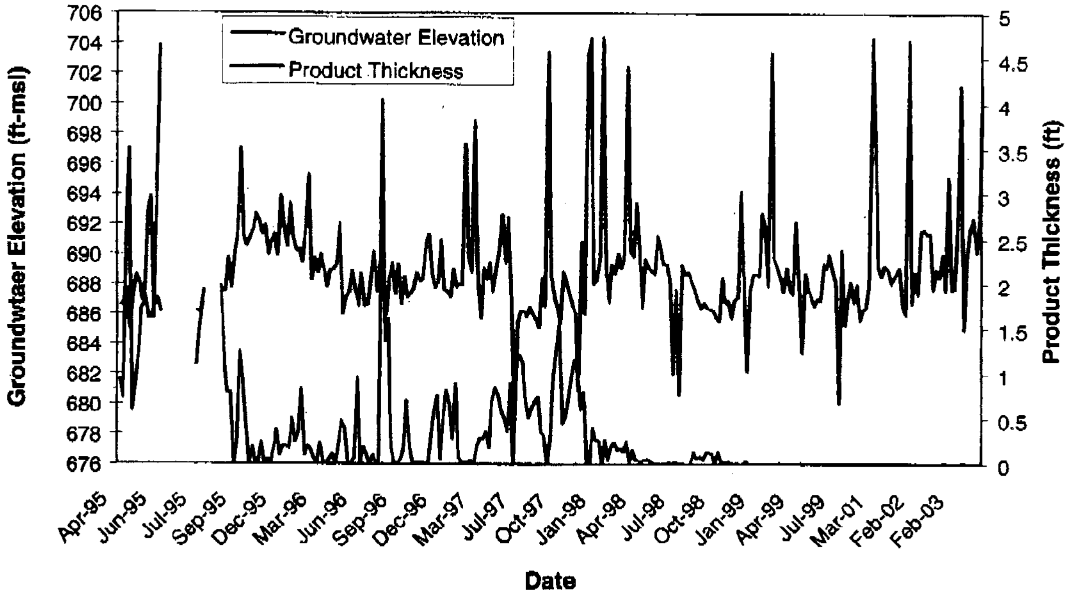


Figure 3.5 Groundwater Elevation and Product Thickness at Extraction Well 4

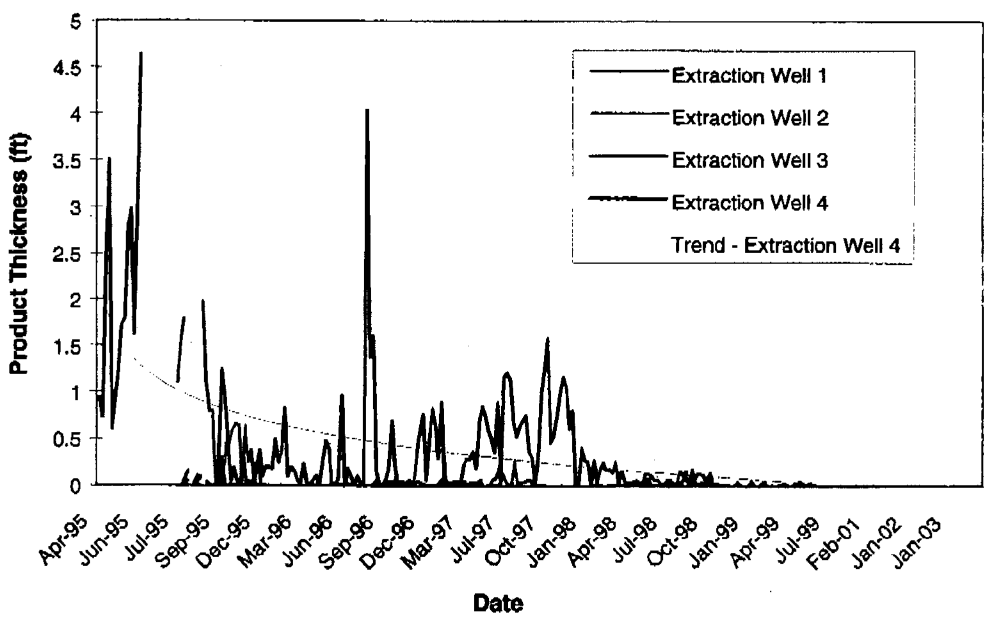


Figure 3.6 Product Thickness at Extraction Wells

3.1.2 Monitoring Wells

Figure 3.7 shows the results of biweekly water level monitoring at wells 4, 22, 23, and the CCW Channel. CCW Channel measurements were obtained from continuous (15-minute frequency) surface water level measurements in the Diffuser Pond. During the monitoring period from May 1995 to September 2003, the CCW Channel water surface has varied from 678.3 to 691.9 ft-msl with an average elevation of 685.9 m-msl. As shown in Figure 3.7, all monitoring wells exhibit slight correlation with water levels in the CCW Channel. With few exceptions, groundwater levels outside of the interceptor trench have remained within a range 682 to 692 ft-msl, which was estimated during design stage of the interceptor system.

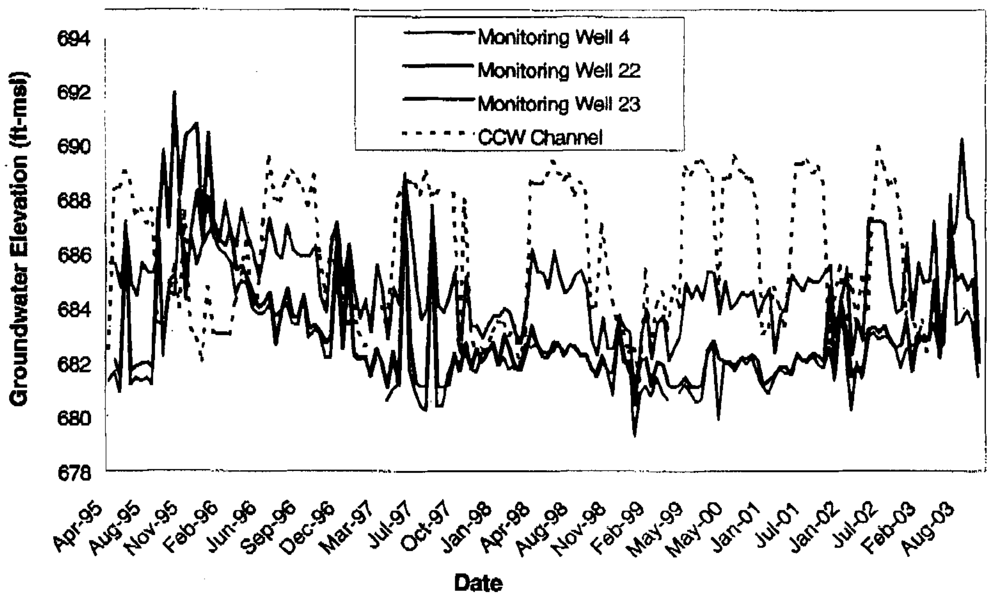


Figure 3.7 Water Levels at Monitoring Wells and CCW Channel

Figures 3.8 through 3.10 show groundwater level and product thickness at monitoring wells with time. The product thickness measurements suggest that fuel oil product is being actively removed from the downgradient (west) side the interceptor trench. Similar to product extraction wells, the current data also indicate declining levels of product at the locations of these monitoring wells. Since July 2001, product thickness has been immeasurable at these locations.

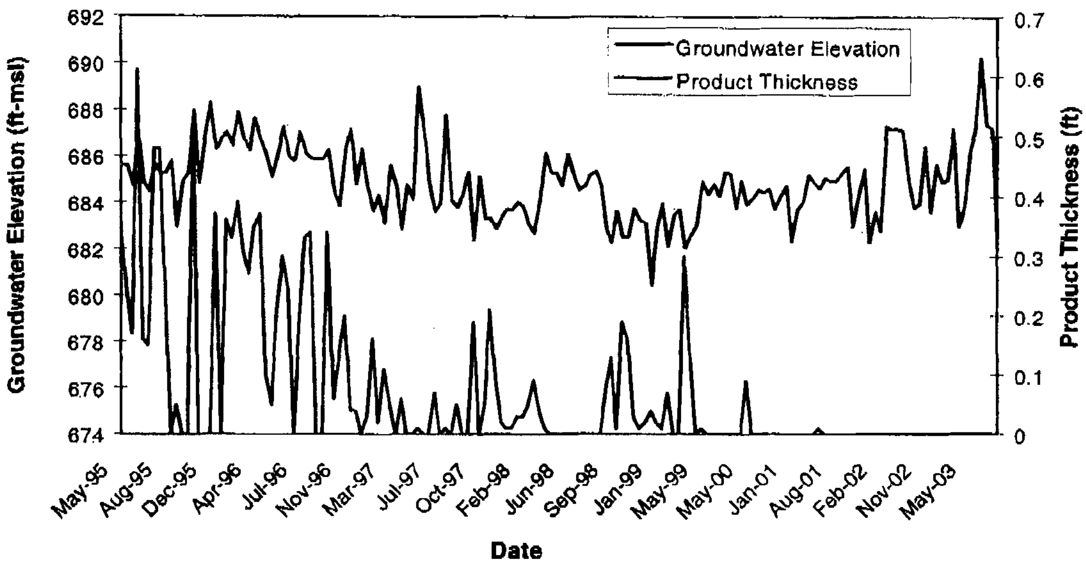


Figure 3.8 Groundwater Elevation and Product Thickness at Monitoring Well 4

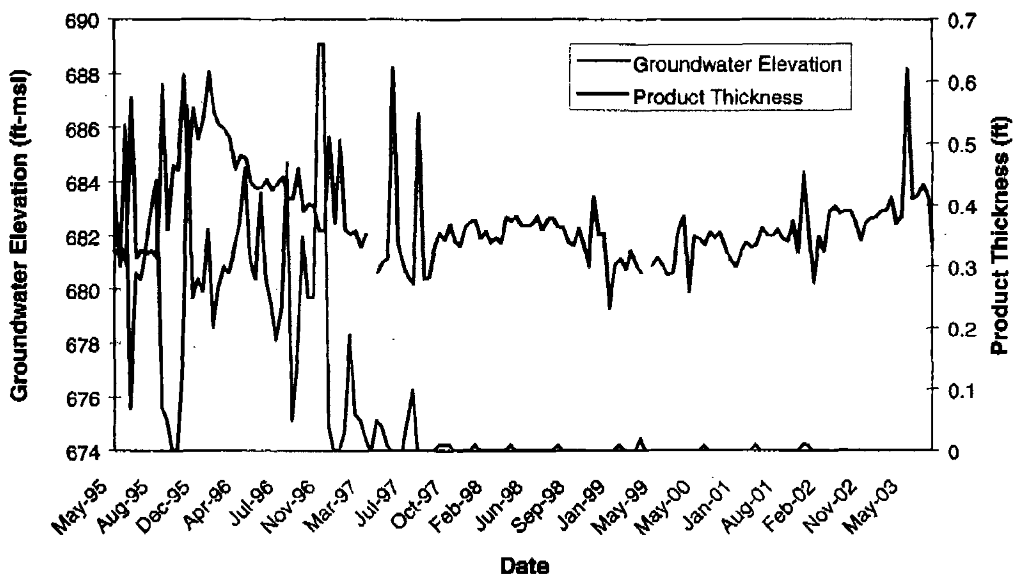


Figure 3.9 Groundwater Elevation and Product Thickness at Monitoring Well 22

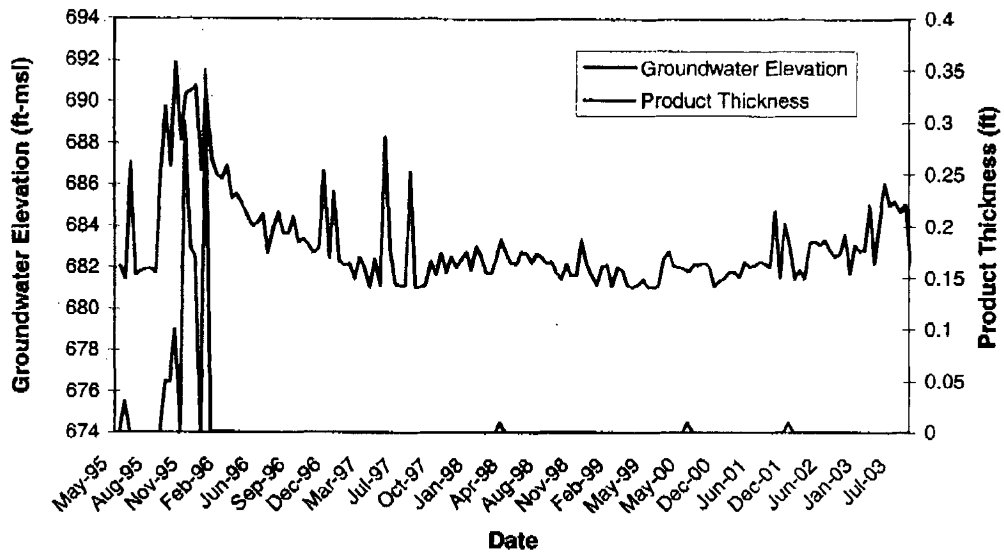


Figure 3.10 Groundwater Elevation and Product Thickness at Monitoring Well 23

Figure 3.11 shows the potentiometric surface at the site from February 10, 2003 based on water level measurements at extraction wells, monitoring wells, and the CCW Channel. The data indicates that drawdown produced by the interceptor trench is within acceptable ranges and the system is performing in accordance with original design.

3.2 Water Quality

3.2.1 Trench Effluent

Currently, groundwater samples of trench effluent are collected biweekly to monthly from a sampling port on the PVC discharge line to the CCW Channel (Figure 3.12). The water quality of effluent from the interceptor trench has been gauged by measurements of TPH and DRO from November 1994 to January 2002, and by EPH analysis since January 2002. TPH measurements have been negligible, and therefore are not shown in Figure 3.12. DRO concentrations ranged from <0.1 to 21 mg/L and the average was 1.1 mg/L from November 1994 – January 2002. EPH concentrations ranged from <0.5 to 4.4 mg/L and the average was 0.9 mg/L from January 2002 to September 2003. As shown in Figure 3.12, data indicate a decreasing trend in petroleum hydrocarbon concentrations with EPH concentrations at or just above detection levels since February 2003.

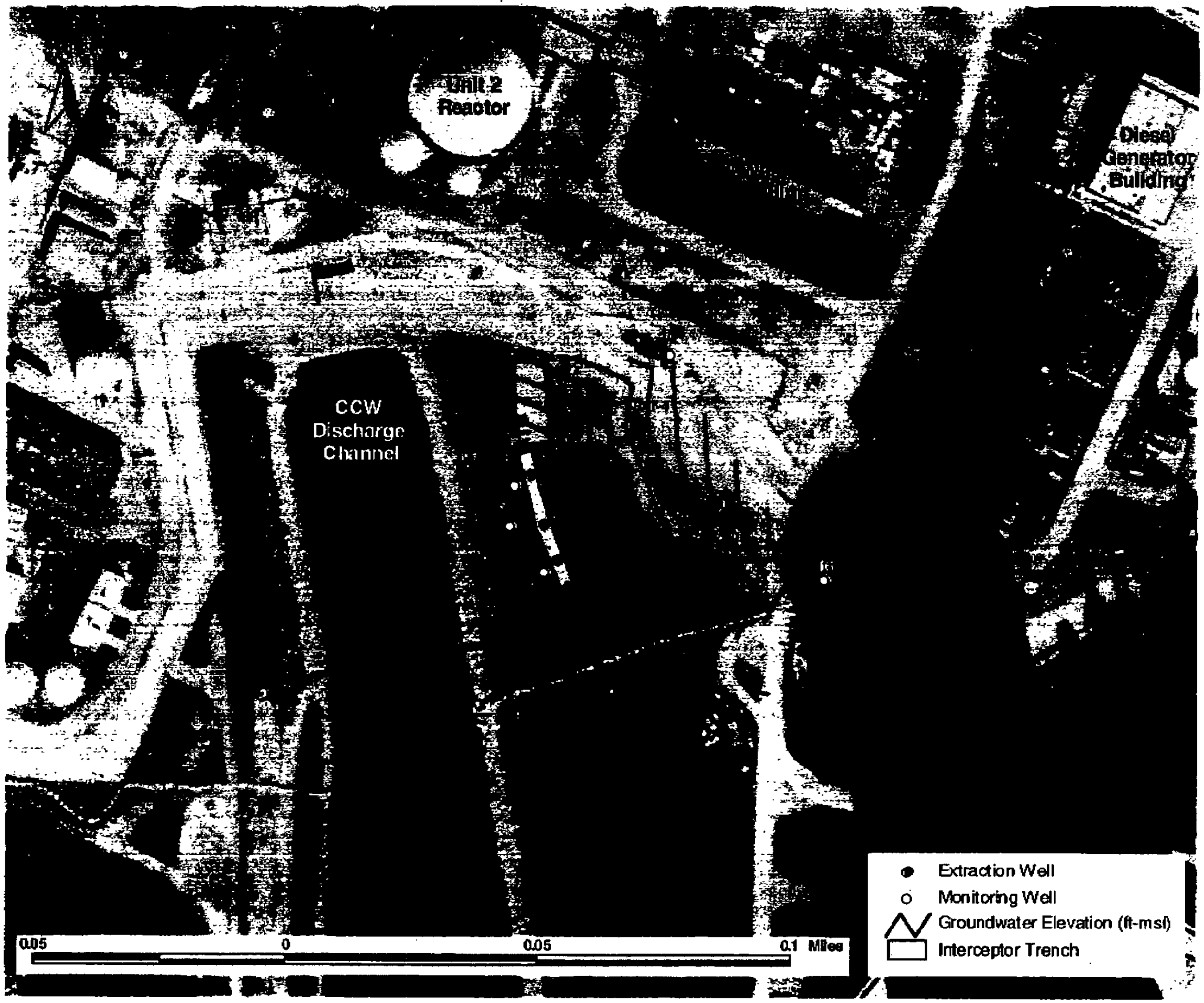


Figure 3.11 Potentiometric Surface at Site from February 10, 2003

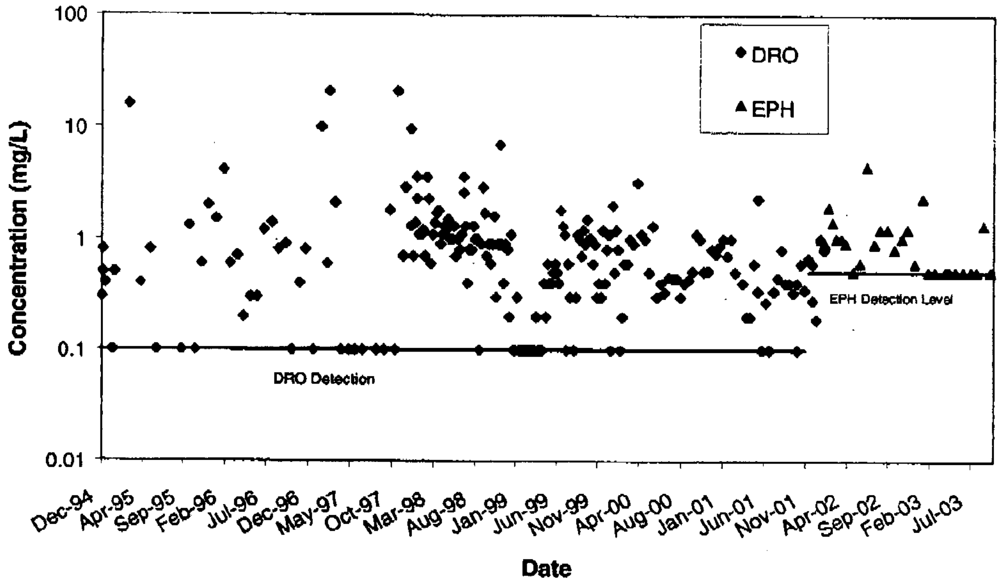


Figure 3.12 DRO and EPH Measurements of Trench Effluent

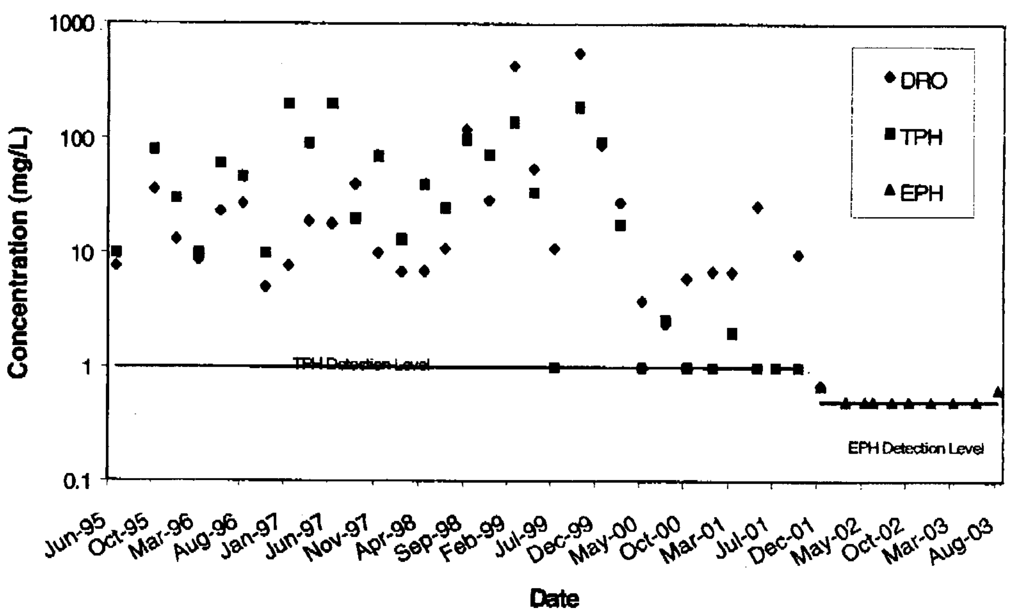


Figure 3.13 DRO, TPH, and EPH Measurements at EXT-4

3.2.2 CCW Channel

Currently, aqueous samples of the CCW Channel are collected monthly at a sampling location downstream of the Interceptor Trench. The water quality of the CCW Channel has been gauged by measurements of TPH and DRO from November 1994 to January 2002, and by EPH analysis since January 2002. With only one exception of DRO (0.51 mg/L on 12/19/01) all measurements of TPH, DRO, and EPH have been less than minimum detection levels.

3.2.3 Extraction Well 4 (EXT-4)

The groundwater samples of EXT-4 are currently collected on a bi-monthly basis. The water quality of EXT-4 has been gauged by measurements of TPH and DRO from November 1994 to January 2002, and by EPH analysis since January 2002. DRO concentrations ranged from <0.1 to 560 mg/L and the average was 52.3 mg/L from November 1994 – January 2002. TPH concentrations ranged from <1.0 to 200 mg/L and the average was 49.9 mg/L from November 1994 – January 2002. As shown in Figure 3.13, data indicate a decreasing trend in petroleum hydrocarbon and diesel range organic concentrations with EPH concentrations at or just above detection levels since January 2002.

4.0 RECOMMENDATIONS FOR TRIAL CLOSURE AND MONITORING

The data collected to date, and a thorough review of site hydrogeologic characteristics and engineered features at the release location, clearly indicate there is no risk to human health or the environment. Therefore, TVA proposes a trial closure of the diesel interceptor system; i.e., turning off all pumps while continuing to monitor water/product levels and water quality (EPH) and maintaining visual observations along the CCW channel. The trial closure will extend for a period of two years. Daily inspections are conducted of all site impoundments and this will continue through the trial closure period. Due to its unique geographical location, there are no downgradient wells located between the site and the Tennessee River. Therefore, the point of compliance will be the CCW Channel. If visual observations of the CCW Channel indicate fuel oil releases or a product thickness of >0.1 ft are noted in extraction or monitoring wells, the interceptor system will be immediately returned to operation and water/product level monitoring frequencies will revert to the original schedule.

At the end of the two-year monitoring period, TVA will submit a report to the Tennessee Department of Environment and Conservation (TDEC) documenting results from trial closure and providing recommendations for final closure and well/trench abandonment.

4.1 Pumping Equipment and Control Panels

Pumping equipment (i.e., depression and product pumps) will be turned off but shall remain in place for the first four months of the trial closure. The equipment shall be maintained on a routine basis to assure operability. Emergency spill equipment and media will be maintained at the site in case of emergency events. Site personnel will follow all other routine maintenance recommendations from vendors for pumping equipment and control panels. If the first four months of trial closure indicate no visual observations of fuel oil releases to the CCW Channel and product thickness remains <0.1 ft (without extraction), pumping equipment will be removed from extraction wells and placed in site storage for the remaining term of trial closure.

4.2 Water and Product Levels

Measuring and recording of groundwater/product levels in all site extraction wells and monitoring wells (except wells 5, 16, and 21) will continue on a bi-weekly basis for three months. The frequency shall be reduced to monthly for the second quarter and subsequently quarterly for one and one-half (1.5) years. Visual monitoring of the CCW Channel will be conducted on a routine basis to inspect for fuel oil sheens near the interceptor trench embankment. An existing telemetry system exists for monitoring water levels in the Diffuser Pond at 15-minute intervals. Assuming no head loss between the CCW Channel gate structure and the Diffuser Pond, this data provides suitable real-time monitoring of CCW Channel levels.

4.3 Water Quality Monitoring

Water quality monitoring shall be conducted at well EXT-4 upgradient of the interceptor trench, wells 22 and 23 downgradient of the interceptor trench, and the CCW Channel (Figure 2.1) on a quarterly frequency for the 2-year monitoring period. Laboratory analysis shall consist of EPH via U.S. EPA Method 8015B.

Signature Page

We, the undersigned, certify under penalty of law, including but not limited to penalties for perjury, that the information contained in this report form and on any attachments, is true, accurate, and complete to the best of our knowledge, information, and belief. We are aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for intentional violations.

TVA Sequoyah Nuclear	Stephanie A. Howard	2/28/06
Owner/Operator (Print name)	Signature	Date
Signatory authority for J. Randy Douet, Site Vice President	Principal Environmental Engineer	
	Title (Print)	
Henry E. Julian, P.E., P.G.	Henry E. Julian	2/10/2006
P.E. or P.G. (Print name)	Signature	Date
	PE: 021114 PG: TN3790	
	Tennessee Registration #	

Note: Each of the above signatures shall be notarized separately with the following statement.

STATE OF Tennessee COUNTY OF Knox

Sworn to and subscribed before me by Teresa M. Householder on this date

February 10, 2006. My commission expires June 7, 2008

Teresa M. Householder	Teresa M. Householder	2-10-06
Notary Public (Print name)	Signature	Date

Stamp/Seal

TERESA M. HOUSEHOLDER STATE OF TENNESSEE NOTARY PUBLIC KNOX COUNTY

Appendix A

Base Case Water Control System Description Tables

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Table A-01 General Project Characteristics

Project	Year Completed	Length of Reservoir (miles)[2]	Miles of Shoreline	Navigation Facilities	Turbine Units (rated capacity in MW)[6]	Turbine Discharge Capacity[6] (total cfs for all units)	
						Most Efficient Load (MEL)	Maximum Sustainable Load (MSL)
Mainstem Projects							
Kentucky	1944	184.3	2,064.3	2 Locks, canal[3]	5 (223)	–[8]	70,000
Pickwick	1938	52.7	490.6	2 Locks, canal[4]	6 (240)	–[8]	89,000
Wilson	1924[1]	15.5	166.2	2 Locks	21 (675)	–[8]	115,000
Wheeler	1936	74.1	1,027.2	2 Locks	11 (412)	–[8]	120,000
Guntersville	1939	75.7	889.1	2 Locks	4 (135)	–[8]	50,000
Nickajack	1967	46.3	178.7	Lock	4 (104)	–[8]	45,000
Chickamauga	1940	58.9	783.7	Lock	4 (160)	–[8]	45,000
Watts Bar	1942	95.5*	721.7	Lock	5 (192)	–[8]	47,000
Fort Loudoun	1943	60.8*	378.2	Lock	4 (155)	–[8]	32,000
Total Mainstem		**663.8**	**6,699.7**	**14 Locks**	**64 (2,296)**		
Tributary Projects							
Norris	1936	129.0	809.2		2 (131)	6,900	9,100
Melton Hill	1963	44.0	193.4	Lock	2 (72)	17,000	22,000
Douglas	1943	43.1	512.5		4 (156)	19,000	24,600[9]
South Holston	1950	23.7	181.9		1 (39)	2,700	3,300[10]
Boone	1952	32.7*	126.6		3 (92)	10,900	13,200
Fort Patrick Henry	1953	10.4	31.0		2 (59)	6,100	9,000
Cherokee	1941	54.0	394.5		4 (160)	15,700	17,800
Watauga	1948	16.3	104.9		2 (58)	2,700	3,300
Wilbur	1912[1]	1.8	4.8		4 (11)	2,500	2,900
Fontana	1944	29.0	237.8		3 (294)	9,000	11,300
Tellico	1979	33.2	357.0	Canal[5]	0[7]	–	–
Chatuge	1942	13.0	128.0		1 (11)	1,500	1,650
Nottely	1942	20.2	102.1		1 (15)	1,420	1,900
Hiwassee	1940	22.2	164.8		2 (176)	8,100	9,800
Apalachia	1943	9.8	31.5		2 (100)	2,700	2,900
Blue Ridge	1930[1]	11.0	68.1		1 (22)	1,600	1,800
Ocoee #1	1911[1]	7.5	47.0		5 (19)	3,200	3,800

Table A-01 General Project Characteristics (continued)

Project	Year Completed	Length of Reservoir (miles)[2]	Miles of Shoreline	Navigation Facilities	Turbine Units (rated capacity in MW)[6]	Turbine Discharge Capacity[6] (total cfs for all units)	
						Most Efficient Load (MEL)	Maximum Sustainable Load (MSL)
Tributary Projects (continued)							
Ocoee #2	1913[1]	–	–		2 (23)	900	1,050
Ocoee #3	1942	7.0	24.0		1 (29)	1,100	1,500
Tims Ford	1970	34.2	308.7		1 (45)	3,700	4,000
Normandy	1976	17.0	75.1		0[7]	–	–
Great Falls	1916[1]	22.0	120.0		2 (34)	2,700	3,700
Upper Bear Creek	1978	14.0	105.0		0[7]	–	–
Bear	1969	12.0	52.0		0[7]	–	–
Little Bear Creek	1975	6.0	45.0		0[7]	–	–
Cedar Creek	1979	9.0	83.0		0[7]	–	–
Total Tributary		**622.1**	**4,307.9**	**1 Lock**	**45 (1,546)**		
Total Projects		**1,285.9**	**11,007.6**	**15 Locks**	**109 (3,842)**		

Notes:

cfs = Cubic feet per second; MW = Megawatts.

1 Projects acquired from others.
2 Normal summer pool. *Fort Loudoun–49.9 miles on the Tennessee River, 6.5 miles on the French Broad River, and 4.4 miles on the Holston River; Watts Bar–72.4 miles on the Tennessee River and 23.1 miles on the Clinch River; Norris–73 miles on the Clinch River and 56 miles on the Powell River; Boone–17.4 miles on the South Fork Holston River and 15.3 miles on the Watauga River.
3 Includes new main lock chamber (110 feet wide and 1,200 feet long) and the Barkley Canal.
4 Tennessee–Tombigbee Waterway; Bay Springs Reservoir is connected to Pickwick Reservoir by a navigation canal.
5 River diversion through a canal increases energy generation at Fort Loudoun.
6 Actual capacity and turbine flows at any time depend on several factors, including operating head, turbine capability, generator cooling, water temperature, and power factor. Capacities and turbine flows include modernization of turbine units (HMODs) already performed, as well as those in the design, construction, or authorization phase. Turbine discharge assumes availability of all units at maximum discharge.
7 Project design does not include power generation capacity.
8 Mainstem projects can be operated well below MSL values but are predominately operated at MSL values because of higher capacities that can be achieved with acceptable loss of efficiency.
9 Primarily operated at this flow rate during flood control operations or emergency power demands.
10 Limited to a flow rate of 3,000 cfs during non-flooding situations to minimize downstream streambank erosion.

Source: TVA file data.

Table A-02 Reservoir Operating Characteristics

Project	Reserved Flood Storage January 1 to Top of Gates[2] (1,000 acre-feet)	Top of Gates Elevations (feet above mean sea level)	Flood Guide Elevations (feet above mean sea level)			Minimum Targeted Summer Level (feet above mean sea level)	Operating Range of Elevations for Run-of-River Projects[4] (feet above mean sea level)
			Jan 1	Mar 15	Jun 1	Aug 1	
Mainstem Projects							
Kentucky	4,008	375	354	354	359	–	
Pickwick	493[3]	418	408	408	414	–	
Wilson	0	507.88	–	–	–	–	504.5–507.8
Wheeler	349	556.28	550	550	556	–	
Guntersville	162	595.44	593	593	595	–	
Nickajack	0	635	–	–	–	–	632–634
Chickamauga	345	685.44	675	675	682.5	–	
Watts Bar	379	745	735	735	741	–	
Fort Loudoun[1]	111	815	807	807	813	–	
Total Mainstem	**5,847**						
Tributary Projects							
Norris	1,473	1,034	985	1,000	1,020	1,010	
Melton Hill	0	796	–	–	–	–	790–796
Douglas	1,251	1,002	940	958.8	994	990	
South Holston	290	1,742	1,702	1,713	1,729	1,721	
Boone	92	1,385	1,358	1,375	1,382	1,382	
Fort Patrick Henry	0	1,263	–	–	–	–	1,258–1,263
Cherokee	1,012	1,075	1,030	1,042	1,071	1,060	
Watauga	223	1,975	1,940	1,952	1,959	1,949	
Wilbur	0	1,650	–	–	–	–	1,635–1,650
Fontana	580	1,710	1,644	1,644	1,703	1,693	
Tellico[1]	120	815	807	807	813	--	
Chatuge	93	1,928	1,912	1,916	1,926	1,923	
Nottely	100	1,780	1,745	1,755	1,777	1,770	

Table A-02 Reservoir Operating Characteristics (continued)

Project	Reserved Flood Storage January 1 to Top of Gates[2] (1,000 acre-feet)	Top of Gates Elevations (feet above mean sea level)	Flood Guide Elevations (feet above mean sea level)			Minimum Targeted Summer Level (feet above mean sea level)	Operating Range of Elevations for Run-of-River Projects[4] (feet above mean sea level)
			Jan 1	Mar 15	Jun 1	Aug 1	
Tributary Projects (continued)							
Hiwassee	270	1,526.5	1,465	1,482	1,521	1,515	
Apalachia	0	1,280	–	–	–	–	1,272–1,280
Blue Ridge	69	1,691	1,668	1,678	1,687	1,682	
Ocoee #1	0	830.76	820	820	829		
Ocoee #2	0	1115.2	–	–	–	–	Not applicable[6]
Ocoee #3	0	1,435	–	–	–	–	1,428 –1,435
Tims Ford	220	895	873	879	888	–[5]	
Normandy	48	880	864	866.7	875		
Great Falls	0	805.3	–	–	–	–	785–800
Upper Bear Creek	0	797	–	–	–	–	790–797
Bear Creek	37	602	565	572.8	576	–	
Little Bear Creek	25	623	603	615	620	–	
Cedar Creek	76	584	560	574.2	580	–	
Total Tributary	**5,979**						
Total Projects	**11,826**						

Notes:

1 Projects are operated in tandem because of diversion canal to increase power generation at Fort Loudoun.
2 The observed flood storage varies, depending on rainfall and runoff.
3 Includes additional storage volume from Bay Springs Reservoir.
4 The observed range varies, depending on demands on the river system.
5 Tims Ford has no August 1 target level; it does have a minimum elevation requirement of 883 feet above sea level from May 15 through October 15.
6 Does not have a permanent pool.

Source: TVA file data.

Table A-03 Minimum Flows, Techniques, Requirements, and Commitments

Project	Techniques	Minimum Flows (cfs)	Frequency and Duration of Flows	Operating Objective
Mainstem Projects				
Kentucky	Appropriate daily scheduling	18,000	Bi-weekly average: June–August	Water supply, water quality
		15,000	Bi-weekly average: May and September	
		12,000	Daily average: October–April	
		5,000	Year-round instantaneous flows if Paducah, Kentucky, stage on Ohio River is greater than 16 feet (occurs about half the time)	Navigation
		15,000	Continuous when Paducah stage is between 14 and 16 feet (occurs about half the time)	Navigation
		20,000	Continuous when Paducah stage is less than 14 feet (occurs about 2% of time)	Navigation
Pickwick[1]	Appropriate daily scheduling	15,000	Bi-weekly average: June–August	Water supply, water quality
		9,000	Bi-weekly average: May and September	
		8,000	Daily average: October–April	
		16,000	Instantaneous when Kentucky headwater is at 354-foot elevation	Navigation
		8,000	Instantaneous when Kentucky headwater is at 355-foot elevation	Navigation
Wilson	Appropriate daily scheduling	8,000	Instantaneous when Pickwick headwater is at or below 409.5-foot elevation	Navigation
Wheeler and Guntersville	Appropriate daily scheduling (45% Wheeler plus 55% Guntersville flows)	10,000	Daily average: July–September	Operation of downstream nuclear plant
		11,000	Daily average: December–March	
		7,000	Otherwise	
Chickamauga	Appropriate daily scheduling	13,000	Bi-weekly average: June–August	Water supply, water quality
		7,000	Bi-weekly average: May and September	
		3,000	Daily average: October–April	

Table A-03 Minimum Flows, Techniques, Requirements, and Commitments (continued)

Project	Techniques	Minimum Flows (cfs)	Frequency and Duration of Flows	Operating Objective
Mainstem Projects (continued)				
Watts Bar	No more than 15 hours of zero flow for holding pond drainage	1,200	Daily average	Operation of downstream nuclear plant
Douglas and Cherokee flows for Knoxville	Appropriate daily scheduling of Cherokee and Douglas along with local inflow	2,000	Daily average	Water supply, water quality
Norris	Turbine pulsing and reregulation weir	200	Daily average: pulse every 12 hours for 30 minutes	Water supply, water quality
For Bull Run fossil plant	Appropriate daily scheduling	800	Daily average: February–March	Thermal compliance–operation of downstream fossil plant
		1,000	Daily average: April–May	
		1,200	Daily average: June	
		1,500	Daily average: July–September	
		2,000	Daily average: October	
		600	Daily average: November–January	
Melton Hill	Appropriate daily scheduling	400	Daily average	Water supply, water quality
Douglas	Turbine pulsing	585	Daily average: every 4 hours for 30 minutes	Water supply, water quality
Douglas for Knoxville	Appropriate daily scheduling of Cherokee and Douglas along with local inflow	2,000	Daily average	
South Holston	Turbine pulsing and reregulation weir	90	Daily average: pulse every 12 hours for 30 minutes	Water supply, water quality
Boone	Turbine pulsing	400	Daily average	Water supply, water quality

Table A-03 Minimum Flows, Techniques, Requirements, and Commitments (continued)

Project	Techniques	Minimum Flows (cfs)	Frequency and Duration of Flows	Operating Objective
Tributary Projects				
Fort Patrick Henry[2]	Turbine pulsing	800	Average 3-hour discharge–year round	Water supply, water quality
		1,250	Instantaneous: January	Operation of downstream fossil plant
		1,300	Instantaneous: February–March	
		1,500	Instantaneous: April–May	
		1,833	Instantaneous: June–September	
		1,450	Instantaneous: October–November	
		1,350	Instantaneous: December	
Cherokee	Turbine pulsing	325	Daily average: every 6 hours for 30 minutes	Water supply, water quality
Cherokee for Knoxville	Appropriate daily scheduling of Cherokee and Douglas along with local inflow	2,000	Daily average	
Watauga measured from Wilbur[3]	Turbine pulsing	107	Daily average: small unit every 4 hours for 1 hour or large unit every 4 hours for 15 minutes	Water supply, water quality
Fontana measured from Chilhowee[4]	Appropriate daily scheduling	1,000	Daily average: May–October Fontana and Santeetlah plus local inflow	Water supply, water quality
Chatuge	Turbine pulsing and reregulation weir	60	Daily average: every 12 hours for 30 minutes	Water supply, water quality
Nottely	Small hydro unit when large unit is not generating	55	Continuous	Water supply, water quality
Apalachia[5]	Turbine pulsing	200	Daily average: every 4 hours for 30 minutes	Water supply, water quality
	Appropriate daily scheduling of discharges from Apalachia and Ocoee #1	600	Daily average	
Blue Ridge[2]	Small hydro unit when large unit is not generating	115	Continuous	Water supply, water quality

Table A-03 Minimum Flows, Techniques, Requirements, and Commitments (continued)

Project	Techniques	Minimum Flows (cfs)	Frequency and Duration of Flows	Operating Objective
Tributary Projects (continued)				
Ocoee #1	Turbine pulsing	140	Daily average: every 4 hours for 1 hour	Water supply, water quality
	Appropriate daily scheduling of discharges from Apalachia and Ocoee #1	600	Daily average	
Tims Ford	Small hydro unit when large unit is not generating	80	Continuous	Water supply, water quality
For Fayetteville	Appropriate daily scheduling	120	Continuous	
Normandy for Shelbyville	Appropriate daily scheduling	40 155	Continuous	Water supply, water quality
Upper Bear Creek		5	Continuous	Water quality, water supply
Bear Creek for Red Bay		21	Continuous	Water quality, water supply
Little Bear Creek		5	Continuous	Water quality, water supply
Cedar Creek		10	Continuous	

Notes:

cfs = Cubic feet per second.

1 Minimum tailwater below Pickwick is maintained at or above a 355-foot elevation for navigation. Continuous minimum discharge from Pickwick is used to maintain this minimum elevation whenever Kentucky headwater is at or below a 355-foot elevation. These discharges vary as the Kentucky headwater varies between elevations of 354 and 355 feet.

2 Fort Patrick Henry is required to supply a minimum flow for the John Sevier Steam Plant that equals the plant cooling water intake plus a minimum bypass flow for the current time of year. The minimum bypass flow is defined as follows in the National Pollutant Discharge Elimination System permit for John Sevier:

> To the maximum extent practicable (considering only the short and long term availability of water for release from upstream impoundments and alternative sources of generation to meet the public demand for power), not less than 350 cfs nor one-third of the plant cooling water flow, whichever is greater, shall be passed over the dam during the period from June 1 to September 30 at any time the plant is in operation. During the winter months, or during the period of October 1 to May 31, the minimum bypass flow shall be 100 cfs. These are the minimum volumes of cold-water to be provided which will ensure the protection of spawning, development and survival of fish eggs, larvae, and fry and to provide living space for fish consistent with classified uses downstream from the diversion dam.

3 Watauga minimum flow is met at downstream Wilbur.

4 Fontana minimum flow is met at downstream Chilhowee Dam.

5 Apalachia plus Ocoee #1 must meet a combined minimum flow of 600 cfs as the combined daily average.

Source: TVA file data.

Table A-04 Ramping Constraints by Project

Project	Number of Turbine Units	Ramping Rate
Watauga	2	Ramp units up and down a maximum of one unit per hour for downstream safety
Cherokee	4	Ramp units up and down a maximum of two units per hour to minimize downstream bank erosion
Douglas	4	Ramp units up and down a maximum of two units per hour to minimize downstream bank erosion
Apalachia	2	Ramp units up a maximum of one unit per hour for downstream safety
South Holston	1	Maximum turbine flow of 3,000 cubic feet per second (cfs) (below Maximum Sustainable Level [MSL] flows) for hydropower needs required to minimize downstream bank erosion; MSL flows allowed for flood control
Pickwick	6	Turbines limited to a ramp rate of 60 megawatts (MW) per hour when ramping up and a maximum of 40 MW per hour when ramping down for downstream navigation and bank stabilization
Kentucky	5	When Paducah stage is greater than 16 feet–maximum hourly discharge variation of one unit per hour When Paducah stage is less than 16 feet but greater than 14 feet–maximum hourly discharge variation of one unit per hour If Kentucky is not spilling–maximum daily discharge variation of 35,000 cfs per day
Chickamauga	4	From November through April, ramp units up and down a maximum of one unit per hour for Sequoyah Nuclear Plant thermal compliance

Source: TVA file data.

Table A-05 Fishery Types, Dissolved Oxygen Targets, and Type of Aeration Facilities at Reservoir Tailwaters

Project	Fishery Type	DO Target (mg/L)	Type of Aeration Facilities
Mainstem Projects			
Watts Bar		4	Oxygen injection
Fort Loudoun		4	Oxygen injection
Tributary Projects			
Norris	Cold-water	6	Turbine venting
Douglas	Warm-water	4	Turbine venting, surface water pumps, oxygen injection
South Holston	Cold-water	6	Turbine venting, aerating weir
Boone	Cold-water	4	Turbine venting
Fort Patrick Henry[1]	Cold-water	4	Upstream improvements
Cherokee	Warm-water	4	Turbine venting, surface water pumps, oxygen injection
Watauga	Cold-water	6	Turbine venting
Fontana	Cold-water	6	Turbine venting
Chatuge[2]	Warm-water	4	Aerating weir
Nottely	Warm-water	4	Turbine air injection
Hiwassee	Cold-water	6	Turbine venting, oxygen injection
Apalachia[3]	Cold-water	6	Turbine venting
Blue Ridge	Cold-water	6	Oxygen injection
Tims Ford	Cold-water	6	Turbine air injection, oxygen injection

Notes:

mg/L = Milligrams per liter.

[1] The first 4 miles below Fort Patrick Henry are classified as a cold-water fishery; below this point, the tailwater is classified as a warm-water fishery.
[2] Chatuge is classified by state standards as a warm-water fishery but has a trout fishery in its tailwater.
[3] Below the powerhouse.

Source: TVA file data.

Table A-06 Year 2030 Additional Net Water Supply Demand by Project

Project	Additional Net Water Demand (cfs)
Mainstem Projects	
Kentucky	49.91
Pickwick	42.39
Tennessee–Tombigbee Waterway flows	968.80
Wilson	23.99
Wheeler	132.45
Guntersville	17.15
Nickajack	21.70
Chickamauga	31.12
Watts Bar	14.44
Fort Loudoun	16.92
Tellico	1.44
Tributary Projects	
Norris	5.44
Melton Hill	21.99
Douglas	43.22
South Holston	3.79
Boone	-8.62
Fort Patrick Henry	167.60
Cherokee	-133.87
Watauga	23.84
Wilbur	–
Fontana	1.42
Chatuge	3.32
Nottely	0.66
Hiwassee	0.30
Apalachia	0.69
Blue Ridge	16.91
Ocoee #1	-9.02
Ocoee #2	–
Ocoee #3	–
Tims Ford	24.01
Normandy	0.00
Great Falls	–
Upper Bear Creek	0.00
Bear Creek	–
Little Bear Creek	–
Cedar Creek	0.00

Note:

cfs = Cubic feet per second.

Source: TVA file data.

Table A-07 Drawdown Limits for Tributary Reservoirs

Project[1]	Description	Drawdown Limits[2]
Apalachia	Concrete	3 feet per day not to exceed 12 feet per week
Blue Ridge	Hydraulic fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
Chatuge	Impervious rolled fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
Cherokee	Concrete and impervious rolled fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
Douglas	Concrete and impervious rolled fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
Fontana	Concrete	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per day not to exceed 12 feet per week
Great Falls	Concrete	2 feet per day not to exceed 12 feet per week
Hiwassee	Concrete	2 feet per day not to exceed 7 feet per week
Norris	Concrete and earth fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
Nottely	Impervious rolled fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
South Holston	Impervious rolled fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week
Watauga	Impervious rolled fill	2 feet per day not to exceed 7 feet per week for 28 feet; then 3 feet per week

Notes:

1 For those reservoirs not shown, the drawdown rate would follow the rate shown for Blue Ridge.
2 Restrictions are based on dam safety and erosion considerations.

Source: TVA file data.

Table A-08 Fill and Drawdown Dates

Mainstem Project	Operating Mode	Reservoir Fill Target Date	Target Date for Start of Reservoir Drawdown
Kentucky	Storage	May 1	July 5; sloped to December 1
Pickwick	Storage	April 5	July 1; 1-foot fluctuation for mosquito control from mid May to mid-September
Wilson	Run-of-river	Mid-April	December 1
Wheeler	Storage	Mid-April	August 1; 1-foot fluctuation for mosquito control from mid-May to mid-September
Guntersville	Limited drawdown	Mid-April	July 1; with 1-foot drawdown to November 1; 1-foot fluctuation for mosquito control from mid-May to mid-September
Nickajack	Run-of-river	–	–
Chickamauga	Storage	Mid-April	July 1; with 1.5-foot drawdown to mid-August, remainder of winter drawdown begins on October 1; 1-foot fluctuation for mosquito control from mid-May to mid-September
Watts Bar	Storage	Mid-April	August 1; 1-foot drawdown to September 1, then begin remainder of winter drawdown
Fort Loudoun[1]	Storage	Mid-April	November 1
Tributary Project	**Operating Mode**	**Reservoir Fill Target Date**	**Date for Start of Unrestricted Reservoir Drawdown**
Norris	Storage	June 1	August 1
Melton Hill	Run-of-river	–	–
Douglas	Storage	June 1	August 1
South Holston	Storage	June 1	August 1
Boone	Storage	Mid-May	Labor Day (follows guide curve)
Fort Patrick Henry	Run-of-river	–	–
Cherokee	Storage	June 1	August 1
Watauga	Storage	June 1	August 1
Wilbur	Run-of-river	–	–
Fontana	Storage	June 1	August 1
Tellico[1]	Storage	Mid-April	November 1

Table A-08 Fill and Drawdown Dates (continued)

Tributary Project	Operating Mode	Reservoir Fill Target Date	Date for Start of Unrestricted Reservoir Drawdown
Chatuge	Storage	June 1	August 1
Nottely	Storage	June 1	August 1
Hiwassee	Storage	June 1	August 1
Apalachia	Run-of-river	–	–
Blue Ridge	Storage	June 1	August 1
Ocoee #1	Storage	May 1	November 1
Ocoee #2	Run-of-river	–	–
Ocoee #3	Run-of-river	–	–
Tims Ford[2]	Storage	Mid-May	October 15
Normandy	Storage	May 1	November 1; usually falls throughout summer to meet downstream minimum flows
Great Falls	Storage	August 1	October 1
Upper Bear Creek	Run-of-river	–	–
Bear Creek	Storage	Mid-April	November 15
Little Bear Creek	Storage	Mid-April	November 1
Cedar Creek	Storage	Mid-April	November 1

Notes:

1 Tellico, connected by canal to Fort Loudoun, has a pool elevation the same as Fort Loudoun. Because Fort Loudoun is targeted to reach its summer pool level by April 15 and its drawdown does not begin until November 1, Tellico has a flat summer pool.

2 Tims Ford, by design and original project allocation, has always been operated with a minimum summer pool level of 883 feet, which applies until October 15.

Source: TVA file data.

Table A-09 Hydro Modernization Projects To Be Completed by 2014

Power Plant	Status in October 2001[1,2]	Runner Performance Planned	Increased Flow[3]
Phase 2 and Phase 3 Projects			
Douglas (Units 1–4)	Phase 3	High efficiency and capacity	Yes
Guntersville (Units 1–4)	Phase 3	Increased efficiency and capacity	No
Raccoon Mountain (Units 1–4)	Phase 3	High capacity	Yes
Fort Loudoun (Units 3–4)	Phase 3	Increased efficiency and capacity	Mix
Boone (Units 1–3)	Phase 2	High efficiency, low flow	Insignificant
Chatuge (Unit 1)	Phase 2	High capacity	Yes
Apalachia (Units 1–2)	Phase 2	Increased efficiency and capacity	Insignificant
Watts Bar (Units 1–5)	Phase 2	Increased efficiency and capacity	Yes
Phase 1 and Not Started Projects			
Cherokee (Units 1–4)	Phase 1	High efficiency, low flow	Yes
Wheeler (Units 1–8)	Phase 1	High efficiency, low flow	Not expected
Wilson (Units 19–21)	Phase 1	Increased efficiency and capacity	Expected
Fort Loudoun (Units 1–2)	Not started	Increased efficiency and capacity	Mix
Wilson (Units 1–4)	Not started	High efficiency	Yes
Wilson (Units 5–8)	Not started	High efficiency	Yes
Ocoee #3 (Unit 1)	Not started	Increased efficiency and capacity	Yes
Nickajack (Units 3–4)	Not started	Increased efficiency and capacity	Yes
South Holston (Unit 1)	Not started	Increased efficiency and capacity	No
Melton Hill (Units 1–2)	Not started	Increased efficiency and capacity	No
Watauga (Units 1–2)	Not started	Increased efficiency and capacity	Yes
Blue Ridge (Unit 1)	Not started	Increased efficiency and capacity	Yes
Wilbur (Units 1–4)	Not started	Increased efficiency and capacity	Insignificant

Notes:

HMOD = Hydro Modernization.
Phase 1 = No plans developed to date; Phase 2 = Design; Phase 3 = Construction.

[1] HMOD projects that have been completed or are scheduled to start soon include:

Tims Ford (Unit 1)	Wheeler (Units 9–11)
Chickamauga (Units 1–4)	Kentucky (Units 1–5)
Wilson (Units 9–18)	Nottely (Unit 1)
Norris (Units 1–2)	Fontana (Units 1–3)
Fort Patrick Henry (Units 1–2)	Hiwassee (Units 2)
Guntersville (Units 1 and 4)	Douglas (Units 2, 3, and 4)
Douglas (Unit 1)	Guntersville (Unit 3)
Raccoon Mountain (Unit 3)	Fort Loudoun (Unit 4)
Guntersville (Unit 2)	Hiwassee (Unit 1)

[2] HMOD projects that were in Phase 2 (design) and Phase 3 (construction) in October 2001 are included in the Base Case. Projects that were in Phase 1 or not started in October 2001 are addressed in the cumulative effects analysis.

[3] HMOD flows for completed projects and those in Phase 2 (design) and Phase 3 (construction) are included in Table A-01.

Source: TVA file data 2001.

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Y-12 Notes

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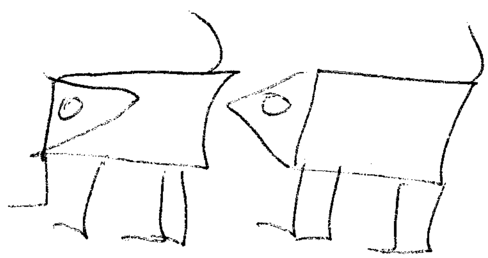

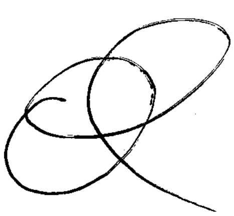

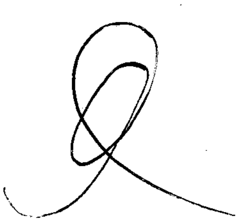

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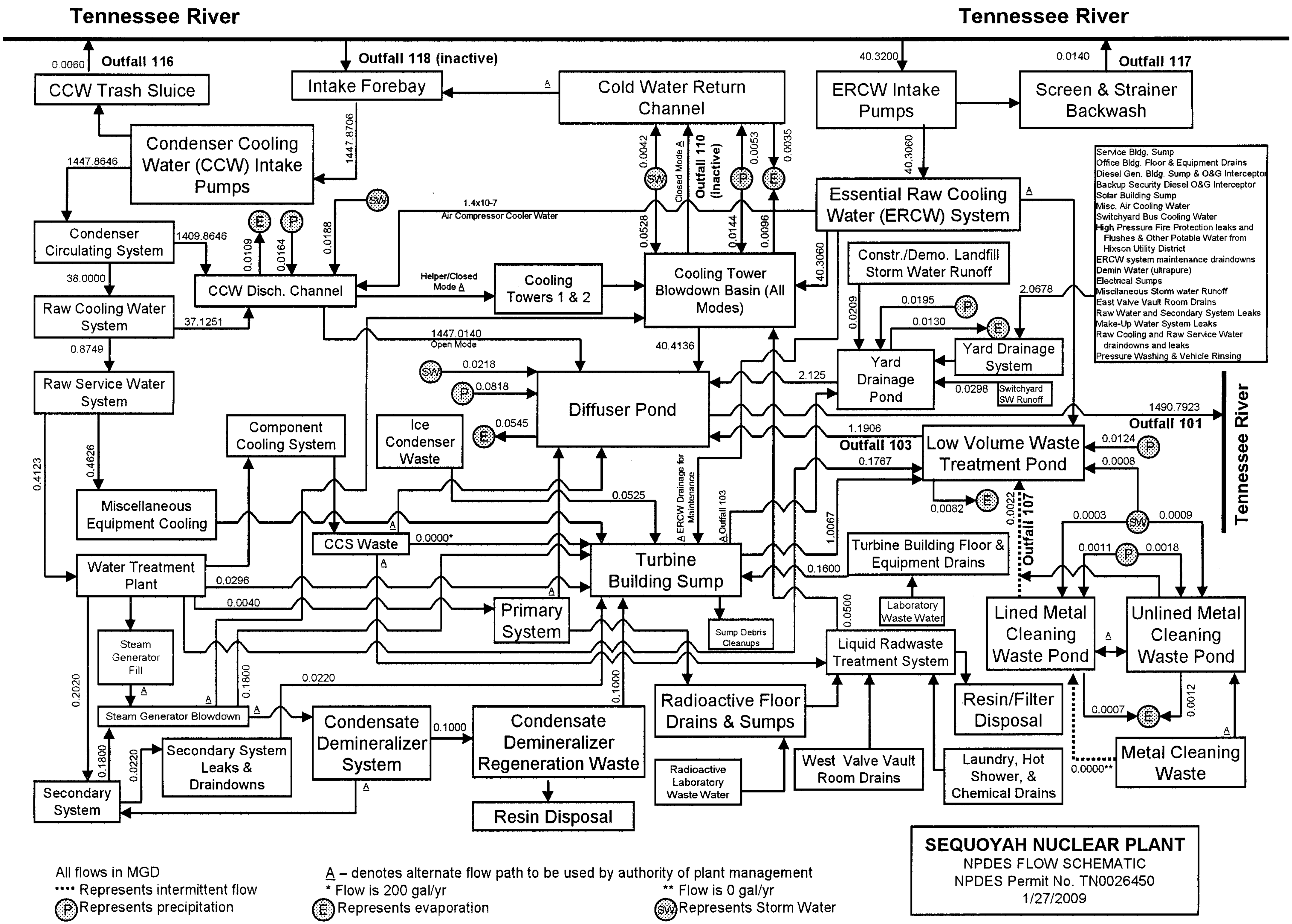
Tennessee River
Tennessee River
Outfall 116
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CCW Trash Sluice
Outfall 118 (inactive)
Intake Forebay
Cold Water Return Channel
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ERCW Intake Pumps
0.0140
Outfall 117
Screen & Strainer Backwash
Condenser Cooling Water (CCW) Intake Pumps
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1447.8706
Condenser Circulating System
1409.8646
CCW Disch. Channel
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Raw Cooling Water System
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Raw Service Water System
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0.4626
Miscellaneous Equipment Cooling
Water Treatment Plant
Steam Generator Fill
Steam Generator Blowdown
Secondary System
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0.1800
0.0220
Secondary System Leaks & Draindowns
Component Cooling System
Ice Condenser Waste
CCS Waste
0.0000*
Primary System
0.0296
0.0040
0.1800
0.0220
Condensate Demineralizer System
0.1000
Condensate Demineralizer Regeneration Waste
Resin Disposal
0.1000
0.0109
0.0164
0.0188
1.4x10-7
Air Compressor Cooler Water
Helper/Closed Mode A
Cooling Towers 1 & 2
Cooling Tower Blowdown Basin (All Modes)
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Open Mode
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0.0042
Closed Mode A
Outfall 110 (inactive)
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0.0035
0.0528
0.0144
0.0096
40.3060
40.3060
Essential Raw Cooling Water (ERCW) System
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0.0818
0.0545
Diffuser Pond
0.0525
Turbine Building Sump
A ERCW Drainage for Maintenance
A Outfall 103
Sump Debris Cleanups
Radioactive Floor Drains & Sumps
Radioactive Laboratory Waste Water
West Valve Vault Room Drains
Liquid Radwaste Treatment System
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Laboratory Waste Water
Turbine Building Floor & Equipment Drains
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1.0067
Resin/Filter Disposal
Laundry, Hot Shower, & Chemical Drains
Constr./Demo. Landfill Storm Water Runoff
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0.0130
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Yard Drainage Pond
Yard Drainage System
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Switchyard SW Runoff
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Low Volume Waste Treatment Pond
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0.0022
Outfall 107
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Outfall 101
Tennessee River
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Lined Metal Cleaning Waste Pond
Unlined Metal Cleaning Waste Pond
0.0007
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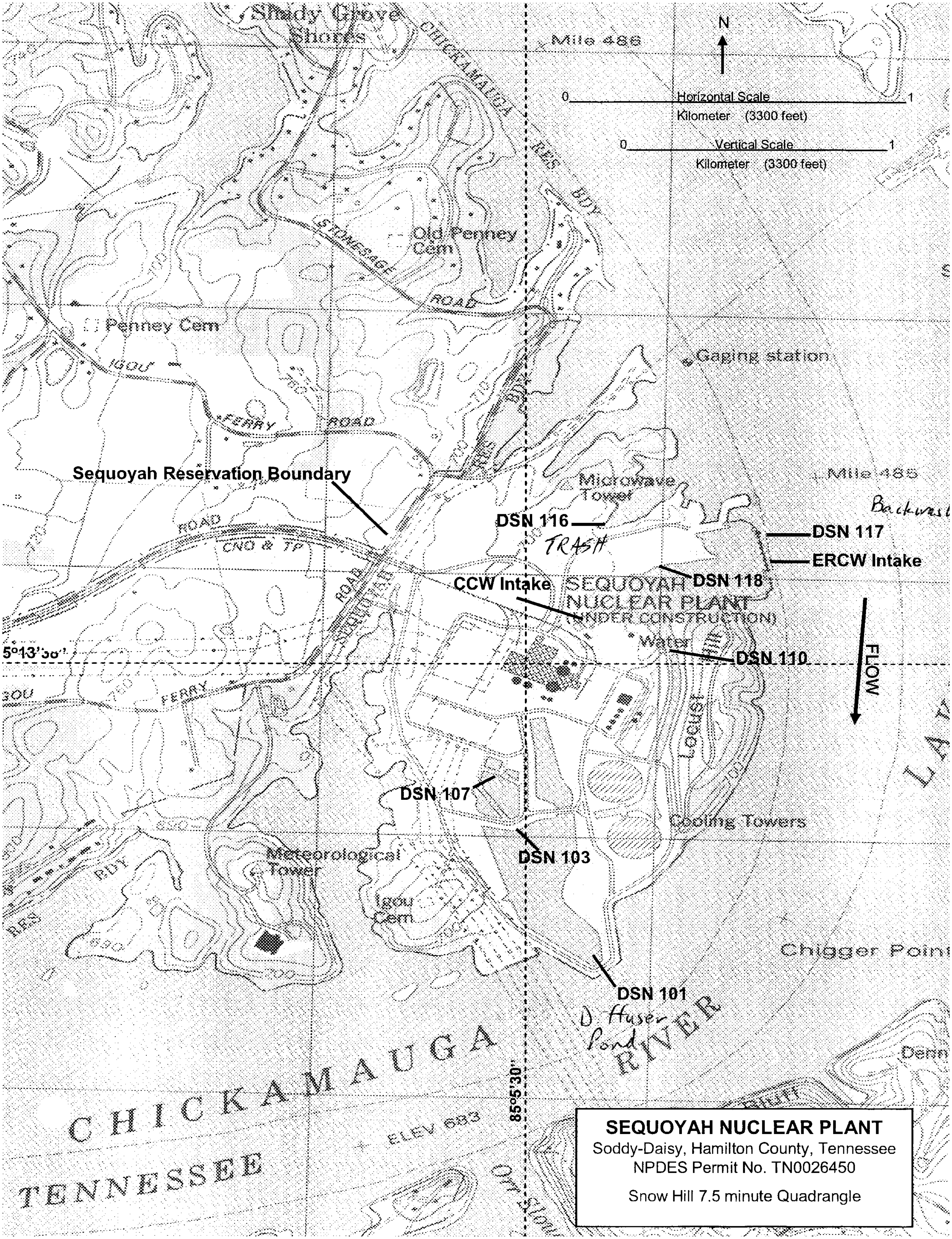
Metal Cleaning Waste
Service Bldg. Sump
Office Bldg. Floor & Equipment Drains
Diesel Gen. Bldg. Sump & O&G Interceptor
Backup Security Diesel O&G Interceptor
Solar Building Sump
Misc. Air Cooling Water
Switchyard Bus Cooling Water
High Pressure Fire Protection leaks and Flushes & Other Potable Water from Hixson Utility District
ERCW system maintenance draindowns
Demin Water (ultrapure)
Electrical Sumps
Miscellaneous Storm water Runoff
East Valve Vault Room Drains
Raw Water and Secondary System Leaks
Make-Up Water System Leaks
Raw Cooling and Raw Service Water draindowns and leaks
Pressure Washing & Vehicle Rinsing
All flows in MGD
•••• Represents intermittent flow
P Represents precipitation
A – denotes alternate flow path to be used by authority of plant management
* Flow is 200 gal/yr
E Represents evaporation
** Flow is 0 gal/yr
SW Represents Storm Water
SEQUOYAH NUCLEAR PLANT
NPDES FLOW SCHEMATIC
NPDES Permit No. TN0026450
1/27/2009



SEQUOYAH NUCLEAR PLANT
Soddy-Daisy, Hamilton County, Tennessee
NPDES Permit No. TN0026450
Snow Hill 7.5 minute Quadrangle