TENNESSEE VALLEY AUTHORITY
River System Operations & Environment
Research & Technology Applications
Environmental Engineering Services - East

RECEIVED
Chattanooga, TN
JUN 22 2010
CNO & EVP Office
TVA Nuclear

BROWNS FERRY NUCLEAR PLANT

INVESTIGATION OF TRITIUM RELEASES TO GROUNDWATER

Prepared by

Hank E. Julian, P.E., P.G.

Knoxville, Tennessee
June 2006

Information in this record was deleted in
accordance with the Freedom of Information Act.
Exemptions 4,5
FOIA/PA 2010-0209

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report has been prepared to document the findings of a groundwater investigation at the Tennessee Valley Authority (TVA) Browns Ferry Nuclear (BFN) Plant site. The investigation was initiated in March 2006 and was targeted towards two locations at the site. The first location is proximal to the cable tunnel which extends from the intake pumping station to the turbine building. Tritium (^{3}H), cesium-137, cesium-134, and cobalt-60 have been observed in recent water samples collected from within the tunnel. The second location is an area associated with the liquid radwaste effluent lines which reside beneath the service bay on the northwest side of the reactor and diesel generator buildings. Tritium has been routinely observed (since January 2001) at low concentrations (<792 pCi/L) in a shallow soil monitoring well (well R3) that was installed specifically for expanded compliance monitoring of the radwaste lines. The primary objectives of the investigation were to:

- Identify potential radionuclide contaminant sources that account for observed measurements,
- Assess the nature and extent of subsurface contamination, and
- Characterize groundwater movement to evaluate potential contaminant migration routes

Field investigations to support this study were conducted from March -- June 2006 by TVA personnel. Major tasks associated with field investigations included (1) redevelopment and sampling of regional bedrock wells, (2) manual sampling of accessible yard drain catch basins, vaults, and manholes, (3) groundwater sampling using Geoprobe methods, and (4) water level monitoring.

Regional bedrock wells 1-5 generally reside on the perimeters of the BFN Reservation. These wells were redeveloped and sampled in March 2006. Laboratory analytical results indicated that tritium concentrations were less than the minimum detection concentration (MDC) of 220 pCi/L.

Manual sampling at 16 locations (catch basins, manholes, and vaults) showed the positive detection of tritium within only four shallow manholes. Tritium was initially observed at concentrations of 516.8 and 279.2 pCi/L, respectively, in MH-318 and MH-319. Subsequent samples from these manholes indicated that tritium was less than the MDC of 222.9 pCi/L. Two shallow (4.6-ft deep) electrical vaults (HH-1-MS and HH-T-5) exhibited low concentrations of tritium (<380 pCi/L). Observation of tritium in electrical vaults HH-1-MS and HH-T-5 is not completely explicable. The vaults possess impermeable covers and the groundwater table resides several feet below the vault bottoms. It is conceivable that the source of tritiated water within the vaults is associated with contaminated groundwater some distance upgradient (N-NW) of the electrical vaults. Electrical conduits (and their bedding materials) intersecting the vaults are probable avenues for groundwater transport into the vaults.

Groundwater sampling at 29 Geoprobe borings showed the positive detection of tritium at only six of these locations. The highest measured concentration of tritium in groundwater (4,325 pCi/L) was observed at BH-25 near the junction of the cable and condensate transfer tunnels. Tritium concentrations suggest a plume extending along the axis of the condensate transfer tunnel. In general, the highest tritium concentrations in the shallow groundwater system are associated with the eastern portion of the site. Although data is sparse for the deeper flow regime (i.e., weathered zone and shallow bedrock), the extent of the tritium plume is reasonably bounded by sampling locations in the horizontal.

Current results suggest that the source of tritiated groundwater is associated with the condensate transfer tunnel. Individual testing of the three active radwaste effluent lines was conducted with no indication of pressure losses. Considering that the condensate transfer tunnel is of concrete construction with numerous expansion joints, tritiated water that might have been released into the tunnel could have found egress via the expansion joints and/or cracks through the tunnel wall. The cable tunnel and condensate transfer tunnel posses a common concrete wall along the majority of the transfer tunnel length. Tritiated water observed in the cable tunnel could have been transported directly through this mutual wall, or could have originated from contaminated groundwater in the immediate vicinity of the cable tunnel. The BFN staff is currently investigating historical aqueous release(s) that might have occurred within the condensate transfer tunnel.

Tritium is a conservative contaminant since it is not susceptible to attenuation via sorption or biochemical degradation. Reduction of tritium concentrations in the groundwater system at BFN will occur primarily by hydrodynamic dispersion and dilution. Dispersion will result in reductions of tritium concentrations with increasing distance from the source (e.g., the condensate transfer tunnel). Dispersion will be more pronounced in the soil horizon relative to the deeper and more transmissive weathered bedrock horizon. However, the fate and transport of tritium in the site groundwater system is also likely to be governed by avenues of relatively rapid groundwater movement that exist within bedding material of larger pipelines and tunnels, along zones associated with soil unraveling (originating from historical dewatering operations), and along the weathered bedrock horizon.

The Unit 1 intake conduit is likely to function as a boundary for groundwater transport on the east side of the tritium plume. Groundwater and surface water level measurements during the study confirm that the return channel will ultimately be recipient to tritiated groundwater discharge from the site. Assuming full mixing, groundwater discharge along a 1,000-ft reach of channel, and complete water displacement during a single day, a groundwater/channel water dilution ratio of about 1:20,000 can be estimated. However, actual dilution ratios in the channel and subsequently the Tennessee River are dependent on plant operation and river flow.

(b)(4),(b)(5)

1.0 INTRODUCTION

Browns Ferry Nuclear Plant (BFN) is a three-unit nuclear power plant located at the Browns Ferry site in Limestone County, Alabama (Figure 1.1) and was designed for initial power levels up to 3293 MWt per unit, under Section 104(b) of the Atomic Energy Act of 1954, as amended, and the regulations of the Atomic Energy Commission set forth in Part 50 of Title 10 of the Code of Federal Regulations (10 CFR 50). Commercial operation of each unit began on the following dates: unit one on August 1, 1974; unit two on March 1, 1975; and unit three on March 1, 1977.

In October 2000, TVA expanded the Radiological Environmental Monitoring Program (REMP) at BFN by installing three additional soil monitoring wells in an area associated with the liquid radwaste effluent lines which reside beneath the service bay on the northwest side of the reactor building (Figure 1.2). Tritium has been routinely observed at low concentrations (<792 pCi/L) in one of the shallow soil monitoring wells (well R3) since sampling was initiated in January 2001. The Nuclear Regulatory Commission (NRC) Site Resident at BFN was notified and is being kept informed as investigations continue.

No tritium or other radionuclides have been detected at levels exceeding background in water samples from monitored public drinking water supplies. No tritium or other radionuclides have been detected at levels exceeding background in groundwater samples from other REMP monitoring wells.

In February 2006, a team consisting of both site and corporate TVA personnel was established to locate the source(s) of the tritium and identify potential path(s) to groundwater. This report provides findings of the site subsurface investigation with recommendations for the path forward. The primary objectives of the investigation were to:

- Identify potential radionuclide contaminant sources that account for observed measurements
- Assess the nature and extent of subsurface contamination, and
- Characterize groundwater movement to evaluate potential contaminant migration routes

Work began immediately on source identification. This work included leak testing of radwaste lines; manual sampling of storm drains, vaults, and manholes; sampling of groundwater wells; and visual inspection of tunnel interiors for evidence of seepage.

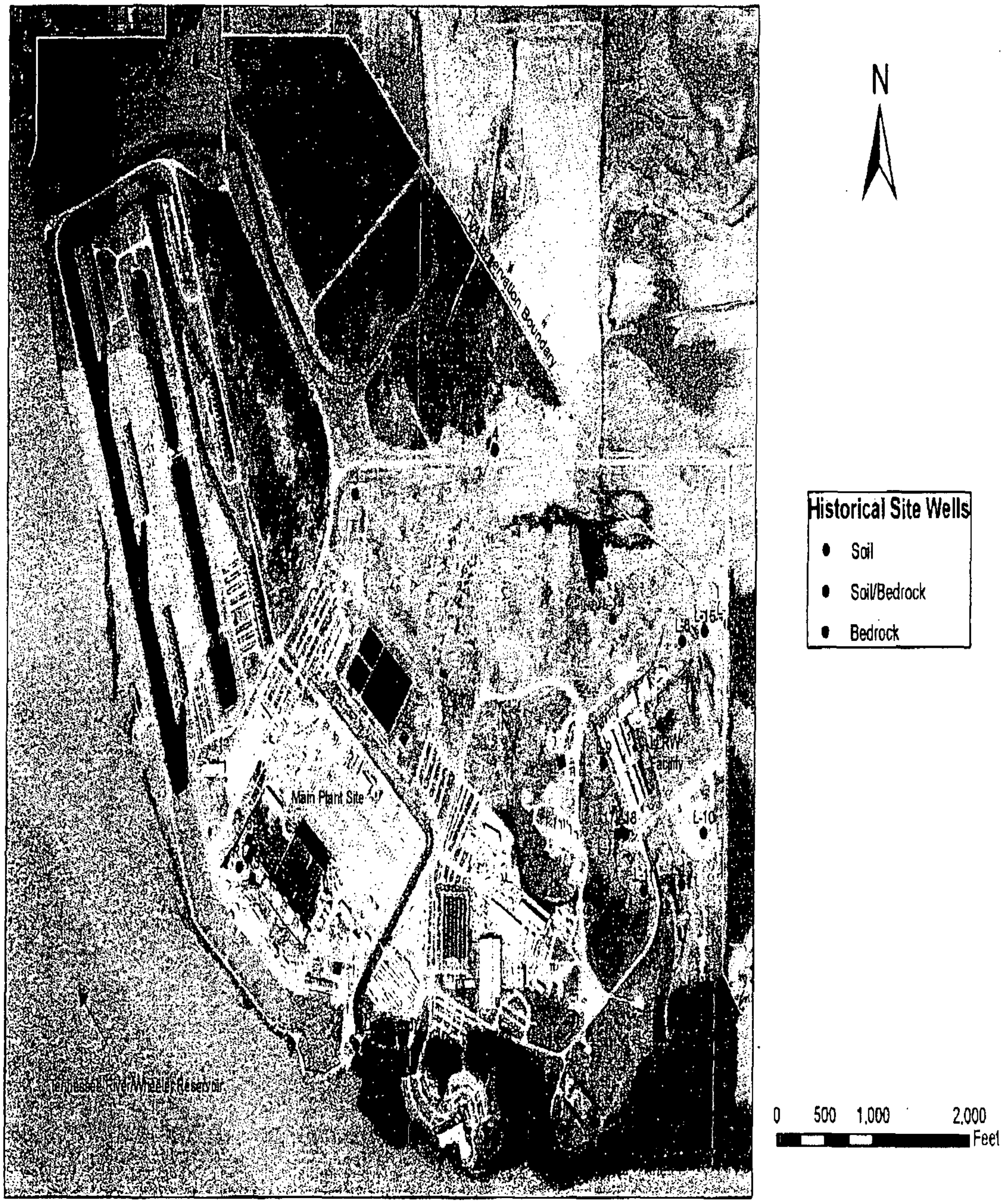


Figure 1.2 Map Showing Historical Site Wells

2.0 BACKGROUND

The monitoring well network at BFN (Figure 1.2) includes six regional monitoring wells (wells 1 – 6) that were installed circa 1984. Well 6 was one of the original pre-operational phase ground water monitoring wells and has always been included in the BFN REMP program. In the earlier years it was sampled by grab sampling. Sometime in the late 1970s or early 1980s the well was equipped with an automatic sampler. From that time to present, the well was sampled daily to generate a composite sample collected each month. Composite water supply samples are analyzed monthly by gamma spectroscopy for gross beta activity and a quarterly composite is analyzed for tritium. Tritium has never detected at the well 6 location.

Eleven groundwater monitoring wells (L-8 – L-18) were installed for the Low-Level Radwaste (LLRW) disposal facility in 1980 and 1981 (Figure 2.1). The wells have been sampled annually for several years and radionuclides have never been detected. In October 2000, TVA added three additional soil monitoring wells (R1, R2, and R3) in an area associated with the liquid radwaste effluent lines which reside beneath the service bay on the northwest side of the reactor building. Tritium has been routinely observed (since January 2001) at low concentrations (<792 pCi/L) in a shallow soil monitoring well (well R3) that was installed specifically for expanded compliance monitoring of the radwaste lines (Figure 1.2).

At the request of its insurance agent, TVA expanded REMP monitoring at BFN by installing three additional soil monitoring wells (R1, R2, and R3) in October 2000 (Figure 2.1). The wells were designed to monitor shallow (soil) groundwater in the immediate vicinity of the liquid radwaste discharge lines. Tritium has been routinely observed at low concentrations (<792 pCi/L) in one of the shallow soil monitoring wells (well R3) since sampling was initiated in January 2001 (Table 2.1).

Liquid pathway monitoring associated with REMP monitoring also includes the collection of samples of river/reservoir water, drinking water supplies, fish, and shoreline sediment. Composite samples of surface water are collected from the Tennessee River using automatic sampling devices from one downstream and one upstream station. The upstream sample is collected from the raw water intake at the Decatur, Alabama, water plant and represents a control sampling location for both surface and drinking water. Composite samples are also collected by an automatic sampling system at the first downstream drinking water intake. At other selected locations, grab samples are collected from drinking water systems that use the Tennessee River as their source. All samples are analyzed monthly by gamma spectroscopy for gross beta activity; quarterly composite samples are analyzed for tritium. Samples of commercial and game fish are collected semiannually from Wheeler and Guntersville Reservoirs and analyzed by gamma spectroscopy. Shoreline sediment from two downstream recreational use areas and one upstream location are collected annually and analyzed by gamma spectroscopy.

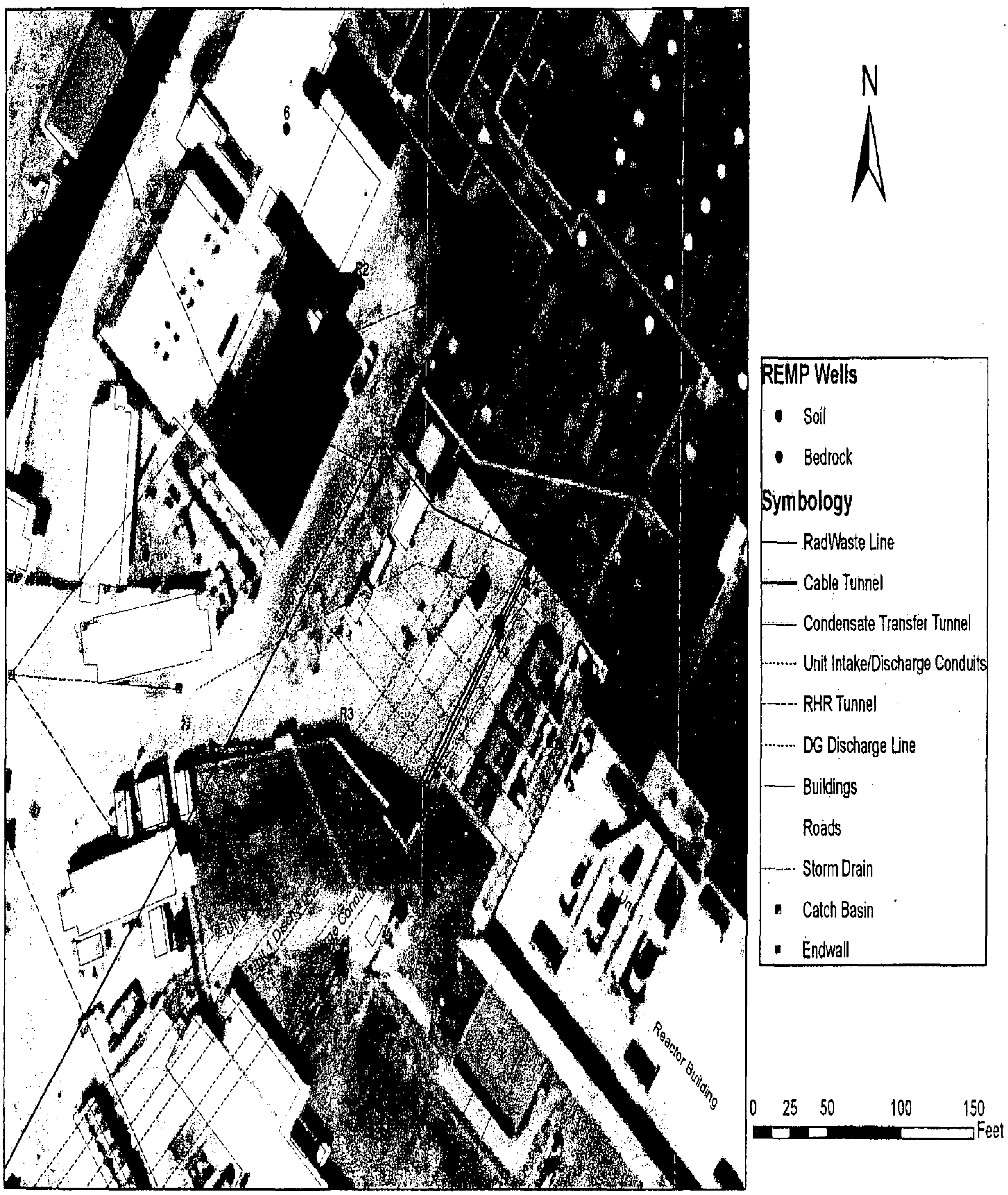


Figure 2.1. Site REMP Groundwater Monitoring Wells

Table 2.1 Tritium Concentrations (pCi/L) in Groundwater Samples from REMP Wells R1, R2, and R3
[Nominal Minimum Detection Concentration (MDC) = 220 pCi/L]

Date	R1	R2	R3
04/18/06	<MDC	<MDC	<MDC
11/22/05	<MDC	<MDC	464
09/23/05	<MDC	<MDC	282
06/09/05	<MDC	<MDC	459
03/16/05	<MDC	<MDC	505
12/03/04	<MDC	<MDC	408
09/23/04	<MDC	<MDC	370
06/16/04	<MDC	<MDC	332
02/27/04	<MDC	<MDC	419
12/19/03	<MDC	<MDC	397
08/22/03	<MDC	<MDC	232
06/05/03	<MDC	<MDC	<MDC
03/11/03	<MDC	<MDC	<MDC
12/23/02	<MDC	<MDC	<MDC
09/25/02	<MDC	<MDC	<MDC
06/13/02	<MDC	<MDC	328
03/22/02	<MDC	<MDC	303
12/20/01	<MDC	<MDC	365
09/06/01	<MDC	<MDC	363
06/12/01	<MDC	<MDC	385
03/22/01	<MDC	<MDC	792
01/16/01	<MDC	<MDC	524

A summary of BFN REMP monitoring (TVA, 2005) indicates that radioactivity in surface water samples was below detection limits except gross beta activity and naturally occurring isotopes. Only naturally occurring radionuclides were observed in shoreline sediments. These results were consistent with previously reported levels. Trace levels of Cs-137 were identified in three fish samples at concentrations consistent with previous monitoring years. The only other isotopes identified in fish samples were naturally occurring radionuclides.

The following components were considered as possible sources of tritium at the site:

1. Liquid Radwaste Effluent Lines
2. Condensate Transfer System

2.1 Liquid Radwaste System and Effluent Lines

2.1.1 Liquid Radwaste System

The Liquid Radwaste System collects, treats, and returns processed radioactive liquid wastes to the plant for reuse. Treated radioactive wastes not suitable for reuse and the suitable liquid waste for reuse whose volume is not needed for plant operations or not desired for reuse are discharged from the plant or packaged for offsite disposal. The Liquid Radwaste System shall be designed to prevent the inadvertent release of significant quantities of liquid radioactive material from the restricted area of the plant so that resulting exposures are within the guideline values of 10 CFR 20, Appendix I of 10 CFR 50, and/or 40 CFR 190.

The liquid radwaste system is divided into several subsystems so that the liquid wastes from various sources can be kept segregated and processed separately. Cross connections between the subsystems provide additional flexibility for processing of the wastes by alternate methods. The liquid radwastes are classified, collected, and treated as high purity, low purity, chemical, or detergent wastes. The terms "high" purity and "low" purity refer to conductivity and not radioactivity.

Low purity (high conductivity) liquid wastes which are collected in the floor drain collector tank are from the following sources:

a. Drywell floor drain sumps,
b. Reactor Building floor drain sumps,
c. Radwaste Building floor drain sumps,
d. Turbine Building floor drain sumps,
e. Chemical waste tank,
f. RHR Systems,
g. Turbine Building backwash and receiver pit floor drain sumps,
h. Turbine Building condensate pump pit floor drain sumps, and
i. Offgas condensate collector sump.

These wastes generally have low concentrations of radioactive impurities; therefore, processing consists of demineralization, filtration, and subsequent transfer to the floor drain sample tank for sampling and analysis. An alternate method of processing low purity wastes is the use of vendor-supplied skid-mounted equipment interconnected to the permanent Radwaste System. After processing, depending on effluent quality and plant needs, the water can be sent to either the waste surge tank or floor drain sample tank.

If analyses indicate that the concentration of radioactive contaminants is sufficiently low and the water is not needed for plant reuse, the sample tank batch is transferred to the circulating water discharge canal for dilution with condenser circulating water as necessary to meet plant effluent discharge requirements of the ODCM. Manual valves are present between the floor drain sample tank and the discharge to preclude the possibility of unanalyzed radioactive water leaking directly to the river.

The ODCM provides the methodology to administratively control limits below regulatory limits. Tritium is typically present in the radwaste effluents. The 10 CFR 20 limit for tritium is 1E-3 μCi/ml; the incremental contribution of the plant release is insignificant compared to current regulatory guidance (TVA, 1999).

Liquid wastes are released at a rate to give Effluent Concentration Limit (ECL) fraction of ≤10 in the discharge canal during the period of the discharge. Since the discharge is on a batch basis, the daily average concentration in the canal is correspondingly less. The discharge from the canal to the environs, therefore, is equal to or less than an ECL fraction of 10. Mixing in Wheeler Reservoir provides additional dilution.

2.1.2 Liquid Radwaste Effluent Lines

There are four liquid radwaste effluent lines located at the BFN site. All radwaste lines are 3-inch ID steel pipe that were originally pressure tested to 150 psi prior to applying protective coating and backfilling. One of the radwaste lines extends from the radwaste building to a 3-ft ID cooling tower discharge line. This line is currently inactive. The three active radwaste effluent lines extend from the radwaste building to three individual induction vaults beneath the service bay on the northwest side of the reactor building (Figures 2.1 and 2.2). These lines reside at a depth of about 2.5-ft below plant grade (565 ft-msl). Discharge from the three active radwaste lines enters each of three 16.5-ft ID unit discharge lines vertically below the induction vaults. Effluent discharge via the three radwaste lines is episodic and is diluted by unit discharge water and ultimately the Tennessee River (at three diffusers).

Because of their proximity to well R3, the radwaste effluent lines were suspected as being the source of tritium release on the northwest side of the reactor and diesel generator buildings. There has been no visible evidence of leakage from the radwaste effluent lines at ground surface. During May 2006, the three active radwaste lines were submitted to individual hydrostatic pressure tests at 50 psi. The three lines exhibited no pressure drop over time intervals exceeding 15 minutes.

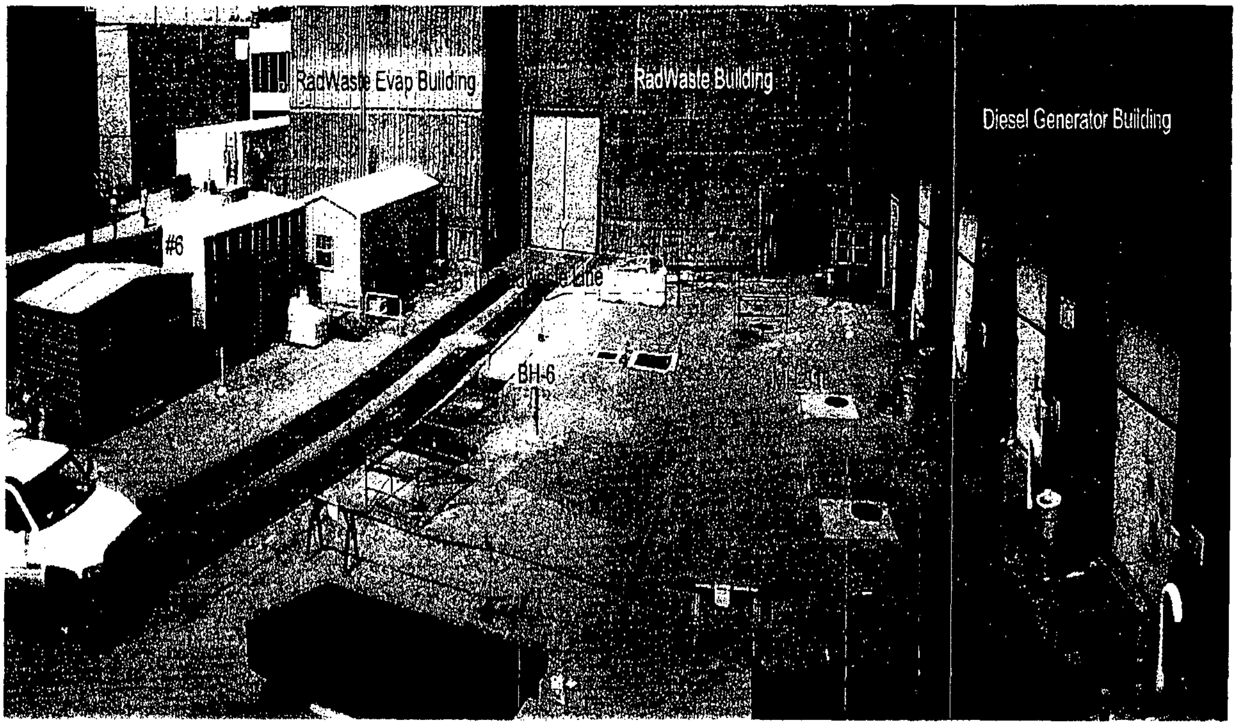


Figure 2.2. Panoramic Photo of Northwest Service Bay (facing northeast)

2.2 Condensate Storage and Transfer System

2.2.1 Condensate Storage System

Condensate is stored in three 375,000-gallon tanks located out-of-doors as shown in Figure 1.1. The tanks are constructed of steel, and are painted inside with a phenolic-epoxy protective coating. Makeup water is supplied from demineralized water storage. Condensate pipelines are contained within a pipe tunnel as shown in Figure 1.1. Two supply return lines per unit connect the storage tanks and lead to the Turbine Building, from which branch lines lead to points of use. These lines consist of one 20-inch ID (steel on Unit 1, aluminum on Units 2 and 3) and one 24-inch ID (aluminum). The 20-inch lines terminate in standpipes within the tanks. These standpipes prevent the level in the individual tanks from being drawn below the 135,000-gallon level via the 20-inch pipe. The 24-inch header terminates in a 20-inch line near the bottom of the tanks. The valves between the tanks and the 20- and 24-inch lines are normally closed to prevent crossload, resulting in a unitized system.

The 20-inch line normally supplies water for non-safety related uses. The line connects directly to the condensate transfer pump suctions and to the condenser hotwells for makeup. The transfer pumps supply water to the following:

- Condensate, cleanup, and fuel pool filter-demineralizers for backwashing;
- Reactor Building operating floor for cooling water flow during dry cask annulus flushing, annulus quenching, alternate cooling operations, decontaminating spent-fuel shipping casks and walls of reactor wells and dryer-separator pits, and for makeup to the fuel pools;
- RHR and core spray systems flush and fill; and
- Floor drain and waste filters and waste demineralizer for backwashing.

The 20-inch line receives return flows from HPCI and RCIC pump tests. The 24-inch line receives return flow from the high-level reject from the condenser hotwells. The latter includes water drained from the reactor well and dryer-separator pit following the refueling, and reactor water released via the Reactor Water Cleanup System during startup.

The 24-inch supply-return header, which has access to the entire volume of the storage tanks, is lined up to supply water to the condensate header in the basement of each Reactor Building, which, in turn, is the primary supply of water to the HPCI and RCIC pumps. The 24-inch supply-return header also provides water to the control rod drive pumps. Water recovered in the radwaste system is returned to condensate storage via the Unit 1 20-inch line.

In addition to the three tanks described above, two 500,000-gallon condensate storage tanks are available for the storage of condensate or for the storage of torus and reactor vessel cavity water during outages. These tanks are located immediately west of tanks numbered 1 -3 in Figure 1.1.

2.2.2 Condensate Transfer System and Cable Tunnel

The Condensate Transfer System includes two centrifugal pumps rated at 1,000 gpm each. A 10,000-gallon head tank is connected into the pump discharge line. The tank is located on the roof of the Reactor Building, approximately 150 feet above the pump. Normally, one pump is used at a time.

The transfer system operates such that small quantities of water are supplied from the head tank, while larger quantities are supplied by the operating pump. The head tank sets the system pressure. When large quantities of water are required, the head tank is valved-off from the rest of the system, and both pumps are placed on manual operation.

If one of the condensate storage tanks is to be taken out of service, the water in it can be transferred to the other storage tanks, using the transfer pumps. Valves are set so that the 20-inch supply-return header is connected to the bottom of the tank to be emptied. The valves in the 24-inch supply-return header are closed to the tank being emptied and open to the tanks being filled. The transfer pump is set to take suction via the 20-inch line and discharge through the 24-inch line. Should an accident occur during the transfer, all of the water in the tanks being filled, and some in the tank being emptied, is available to the safety related systems. The only operator action required is to open the valve in the 24-inch line and to stop the transfer pumps before the suction is lost from the tank being emptied.

Primary condensate transfer lines (e.g., 20- and 24-inch lines) reside within a concrete tunnel that extends between the three primary condensate storage tanks and condensate headers in the basement of the reactor building (Figures 1.1 and 2.3). The transfer tunnel shares a common wall with the cable tunnel (Figures 2.3 and 2.4) along two-thirds of its reach. As shown in Figure 2.4 (detail G1-G1), the condensate transfer tunnel is 8-ft wide x 10.5-ft high and the cable tunnel is 4-ft wide x 10.5-ft high along this route. Construction of the common condensate and cable tunnel required the installation of 0.5-inch expansion joints along its length. TVA design drawing 41N222 indicates that expansion joints were installed at linear distances ranging from about 10 to 40 linear feet. Expansion joints utilized PVC seals with pre-molded joint filler. Backfill of the tunnels was specified as clay in 6-inch layers at 95% optimum density.

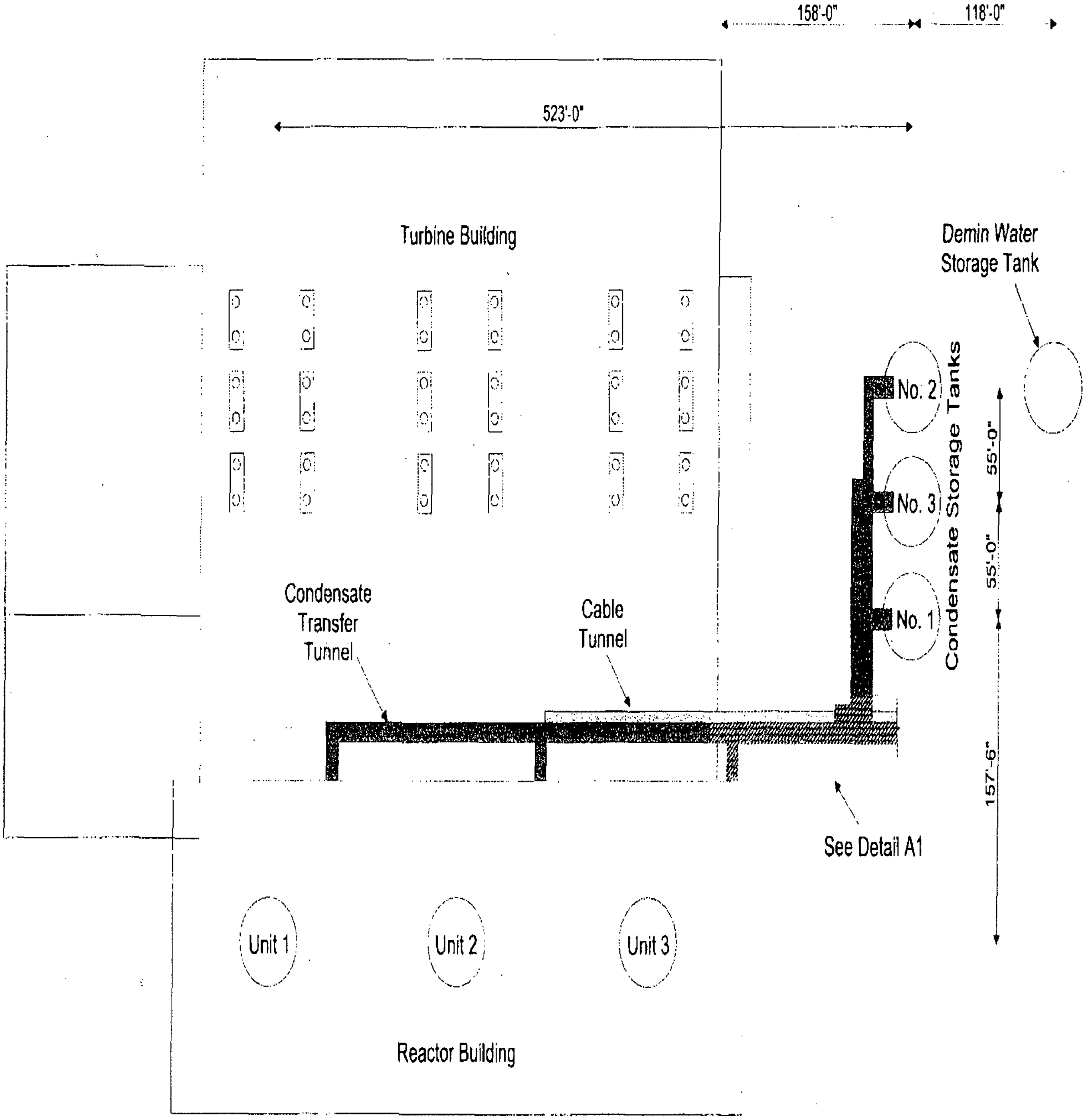
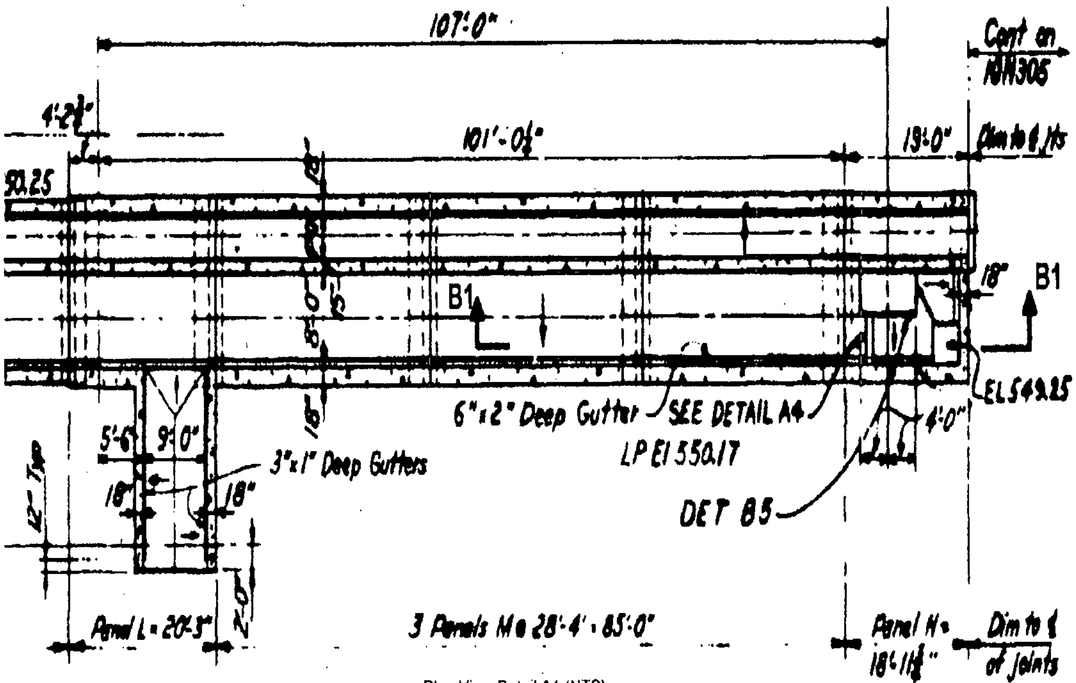
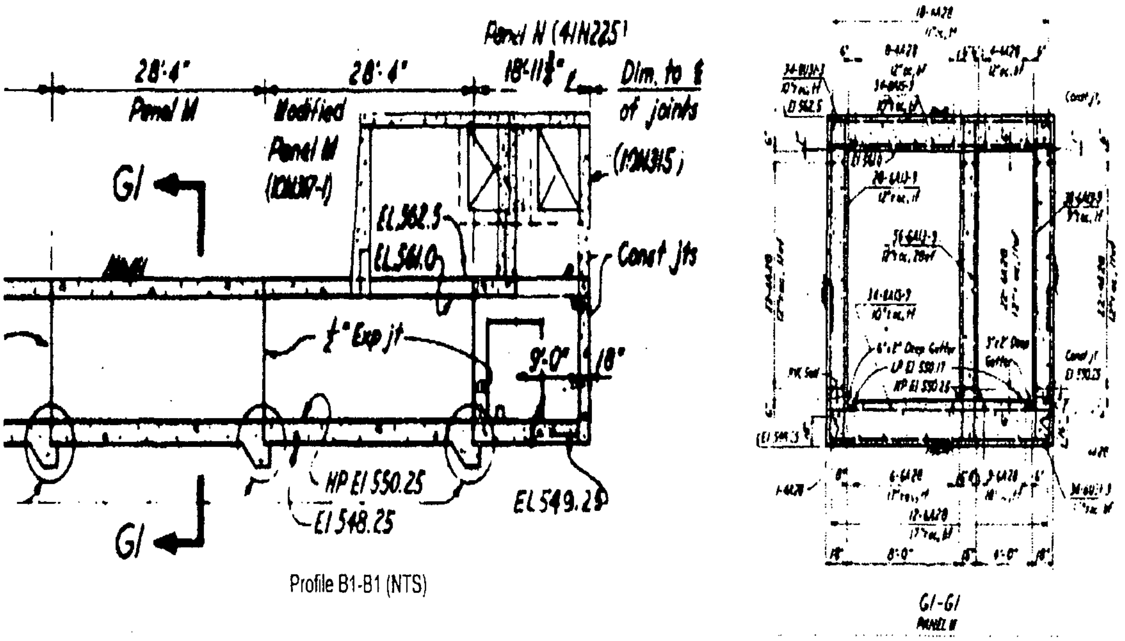


Figure 2.3. Plan View Schematic of Condensate Transfer Tunnel and Cable Tunnel (adapted from TVA Design Drawing 0-17W510)



Plan View Detail A1 (NTS)



Profile B1-B1 (NTS)

Figure 2.4. Details of Condensate Transfer Tunnel and Cable Tunnel (from TVA Design Drawing 41N222)

The cable tunnel extends from the intake pumping station to the turbine building as shown in Figure 1.1. The majority of the cable tunnel consists of 7-ft diameter precast concrete pipe along a 336-ft reach from the intake pumping station to a transition bend toward the turbine building (Figure 2.5). The section of cable tunnel from the bend to the turbine building is approximately 4-ft wide x 10.5-ft high as depicted in Figure 2.4 (detail G1-G1). The reach of the 7-ft ID tunnel pipeline was installed at a grade of 0.33% (downwards) toward the pumping station. TVA design drawing 10N304 indicates that the pipeline was installed in wet compacted sand bedding to about 1/3 of the pipe height (Figure 2.5). The cable tunnel route is depicted on the panoramic photo shown in Figure 2.6.

The condensate storage tanks are inspected at appropriate intervals to ascertain the condition of the protective coating, and routine inspection and maintenance are performed on valves, pumps, and piping. No special tests of the Condensate Storage and Transfer System are required.

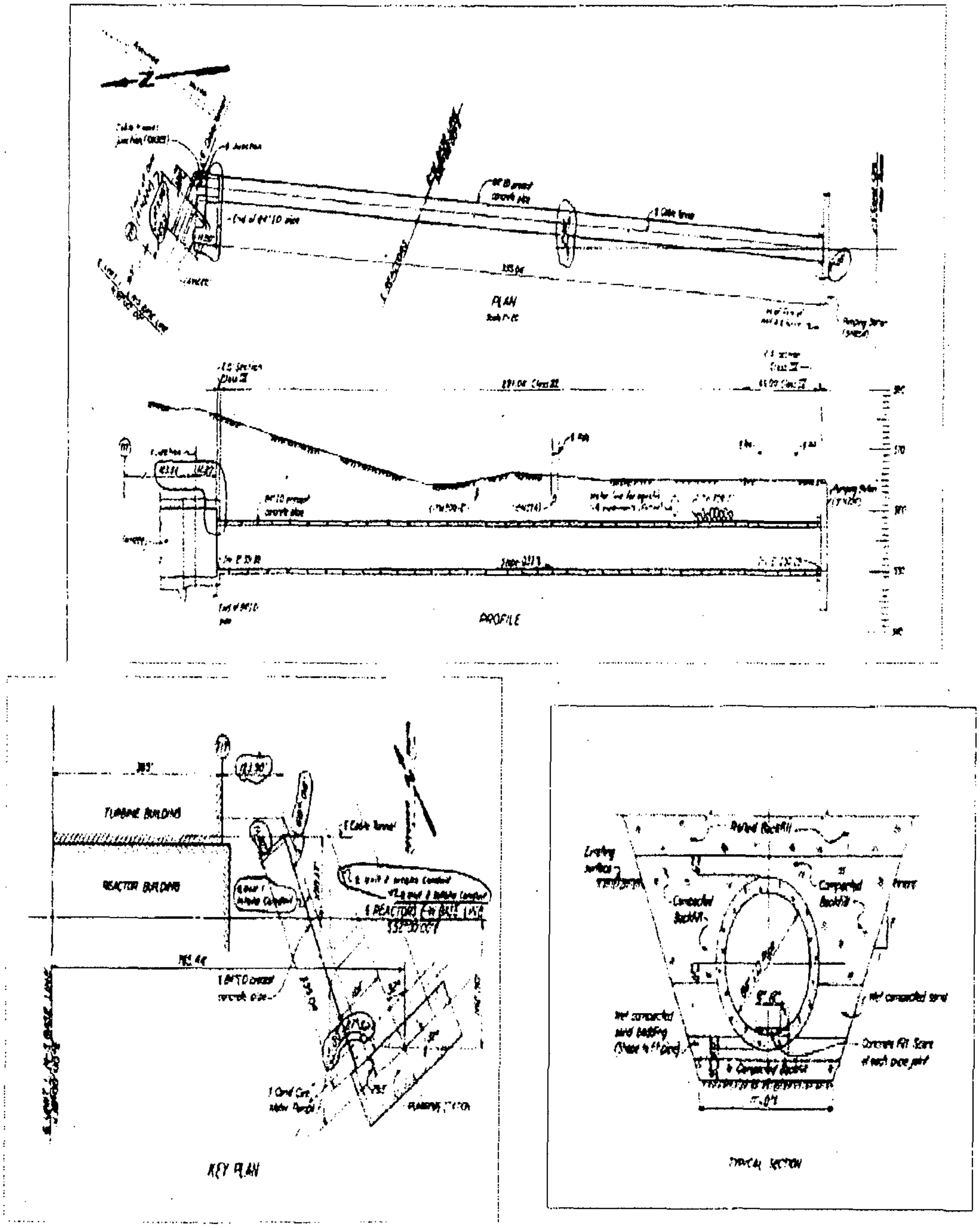


Figure 2.5. Cable Tunnel Plan, Profile, and Section (adapted from TVA Design Drawing 10N304A)

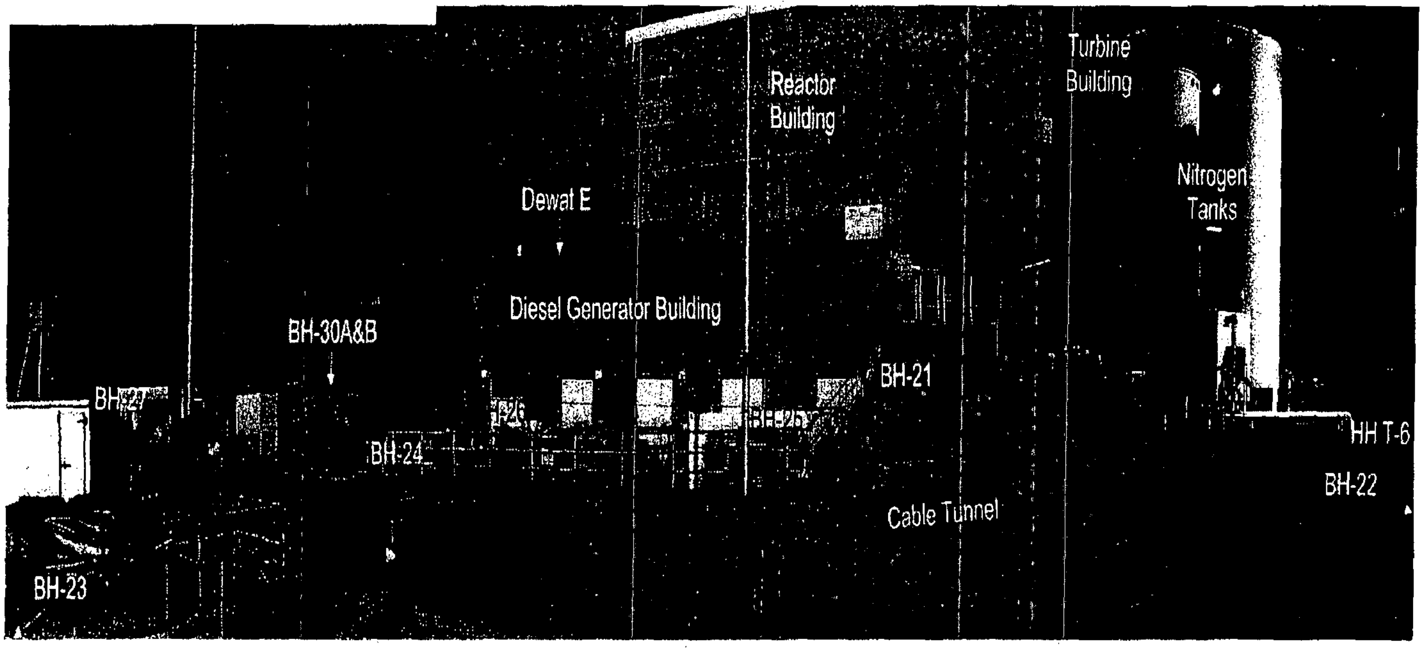


Figure 2.6. Panoramic Photo of Southeast Service Bay (facing west)

3.0 Hydrogeology

3.1 Physiography

The BFN site is located in the Interior Low Plateaus, a plateau lying on the southern flank of the Nashville Dome in northern Alabama. The Nashville Dome is a broad structural arch centered in central Tennessee and extends from Alabama to Kentucky. Erosion over a long period of time has stripped off Pennsylvanian and younger Mississippian clastic rocks to expose Mississippian limestone formations throughout much of this region. A young-to-mature karst plateau of moderate relief characterizes this region.

The plant site occupies a former river terrace with an average elevation of 575 ft-msl. This terrace was an older floodplain of the Tennessee River and was developed when the river flowed at a higher stage. Wheeler Lake now covers the most recent floodplain. Surface runoff in the area flows via Poplar Creek, Douglas Branch, and Round Island Creek to the Tennessee River.

3.2 Geology

Initial subsurface geologic investigations were made at the BFN site from January to May 1962, and again during February and March 1963. During these periods, 80 boreholes were installed at the site with the majority of holes penetrating less than 20 ft of bedrock. In 1966, 124 additional borings were drilled in the main plant area to provide additional geologic information. Subsequent subsurface investigations at the site have been conducted as needed to assist in characterization at the Access Highway Bridge, LLRW Storage Facility, a proposed cooling tower site east of the existing cooling towers, and other smaller site appurtenances. Figure 3.1 depicts the locations of historical borings installed for foundation investigations in proximity of the main plant site.

The BFN Final Safety Analysis Report (TVA, 1999) provides a description of the regional and plant site geology. Of the Paleozoic sedimentary formations in the site region, the lower Tuscumbia limestone and Fort Payne chert of Mississippian age provide the foundations for major plant structures.

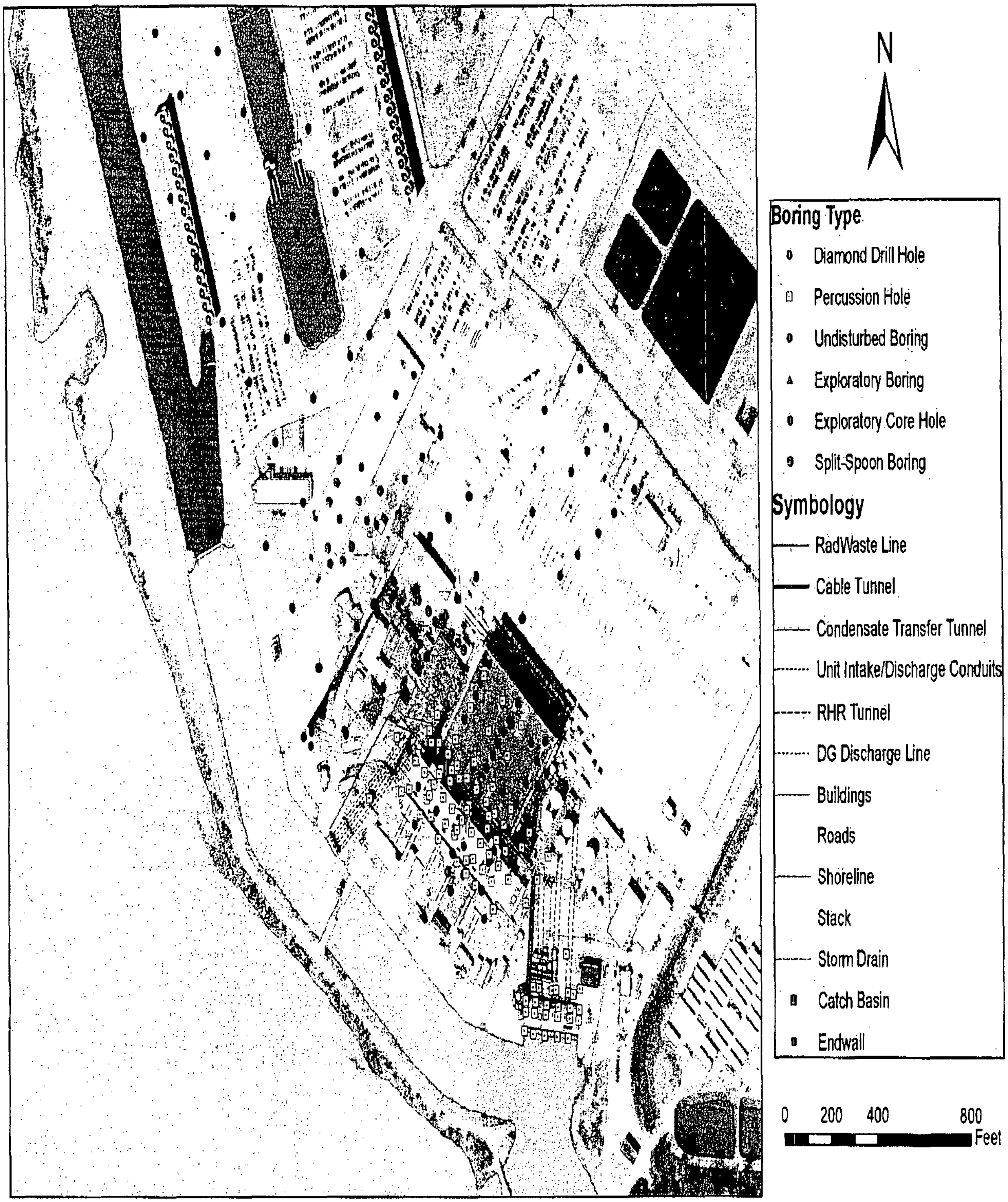


Figure 3.1. Locations of Borings Associated with Historical Foundation Investigations

In the main plant area, the original ground surface occurred at approximately 15 feet above final grade (near elevation 565 ft-msl) in the area of main structures. Within the area of the site, bedrock was mantled by an average thickness of 54 ft of unconsolidated terrace deposits and residual soils. The terrace deposits were of alluvial origin and consist of sandy/silty clays that originally existed from ground surface to depths of 15 to 20 feet in the site area. During plant construction, these deposits were designated as preferred borrow. Underlying the terrace deposits are approximately 40 ft of residual clays and silts interbedded with lateral zones of chert gravel. Differential weathering has produced a zone of material above bedrock that consists of cherty gravel in a matrix of silty clay.

The Tuscumbia limestone is the uppermost bedrock unit underlying the northwestern portions of the BFN site (Figure 3.2). Only the lower 50 feet of the Tuscumbia limestone was encountered at site. The Tuscumbia is absent in areas on the southeast part of the site due to a combination of advanced weathering and stream erosion. The Tuscumbia is characterized by medium to thick beds of light gray, medium to coarse crystalline, fossiliferous limestone. The Tuscumbia is also characterized by abundant light-colored chert. Chert nodules are concentrated in relatively thin stratigraphic units which alternate with non-cherty to slightly cherty units throughout the full thickness of the formation. However, the cherty units are too laterally discontinuous to serve as stratigraphic markers. During excavation for major structures, frequent near-vertical solution features and fractures were observed along steeply dipping joints. Where these features appeared to pinch-out, the major indications of solution activity were near-horizontal zones of weathering developed along bedding. The Fort Payne chert conformably underlies the Tuscumbia Limestone and the contact is commonly gradational.

The maximum thickness of the Fort Payne formation in northern Alabama is slightly over 200 feet. At the site, the total thickness penetrated in one drill hole was 145 feet. The formation consists of medium-bedded, medium to dark gray, silty dolomite and siliceous limestone with a few thin horizons of shale. Near the top of the formation, some of the beds are cherty and some core samples displayed slightly asphaltic zones. The silty, siliceous nature of the formation inhibits the development of solution cavities and few were found during exploratory drilling in this formation. In general, excavation grades for the major structures of the plant (i.e., turbine and reactor buildings) were set in the Fort Payne formation.

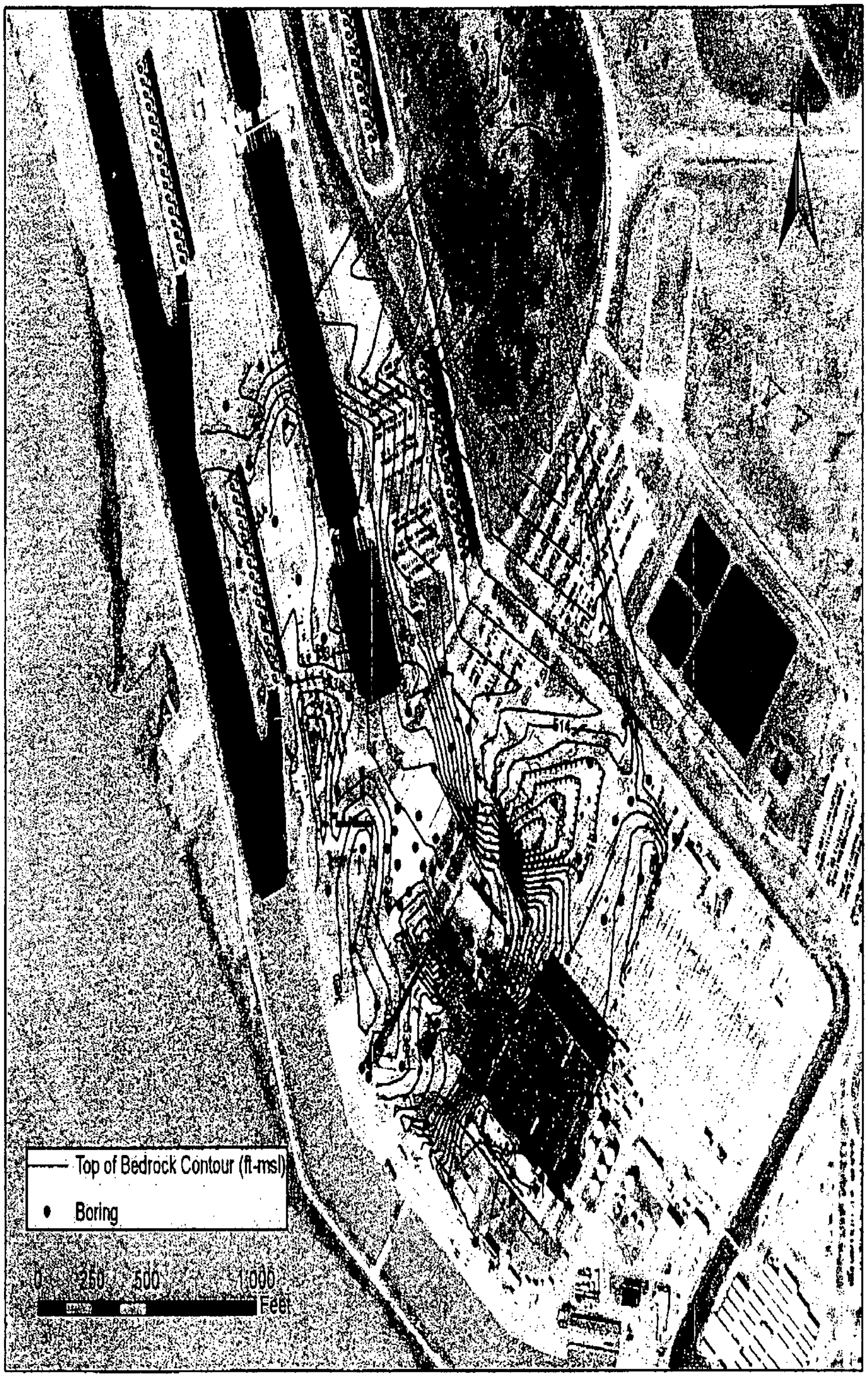


Figure 3.2 Top of Bedrock Map

In the immediate site area, the beds of the Tuscumbia and Fort Payne formations are essentially horizontal. Calculations based upon the elevations at which the contact was encountered between the formations indicate that the direction of dip varies considerably, but has an overall westward component. During its history, this immediate region has been one of little structural deformation. Major folds and faults are entirely absent. The rock strata exhibit slight local folding with regional dips of less than one degree to the southeast away from the Nashville Dome. Rock strata have a regional dip of about 20 ft/mi to the S-SW.

3.3 Groundwater

Recharge to the groundwater system at the plant site is derived primarily from precipitation (about 52 in./yr). Regional water balance studies (Zurawski, 1978) show that approximately 10 to 13 inches of this precipitation enters groundwater storage. Prior to the current study, a total of 18 monitoring wells had been installed at the BFN site since 1980 (Figure 1.2). Bedrock wells 1 – 7 were installed circa 1984; however, well 7 was destroyed during construction of an ancillary structure. Eleven groundwater monitoring wells (L-8 – L-18) were installed for the LLRW Disposal Facility in 1980 and 1981. In October 2000, TVA added three additional soil monitoring wells (R1, R2, and R3) in an area associated with the liquid radwaste effluent lines (northwest side of the reactor building). Well construction diagrams are provided in Appendix A.

Groundwater level measurements were initially collected on an approximately monthly frequency through 1992 at monitoring wells 1-7 (Figure 3.3). Groundwater levels at the site are generally highest during the months of January through March. During September and October, water levels are usually at minimum. Surface water levels in the Tennessee River and plant water channels influence groundwater levels (e.g., well 7; Figure 3.3) and gradients in areas proximal to these features. The direction of regional groundwater movement is generally W-SW toward the Tennessee River based on historical and recent potentiometric mapping (Figure 3.4). Exceptions to this directional flux have been observed to occur at the plant site during dewatering operations (1969-1984) that reversed gradient conditions; in the vicinity of leaking water lines serving the site; in areas of topographic highs/lows; and in the vicinity of the LLRW storage facility where more complex groundwater movement exists.

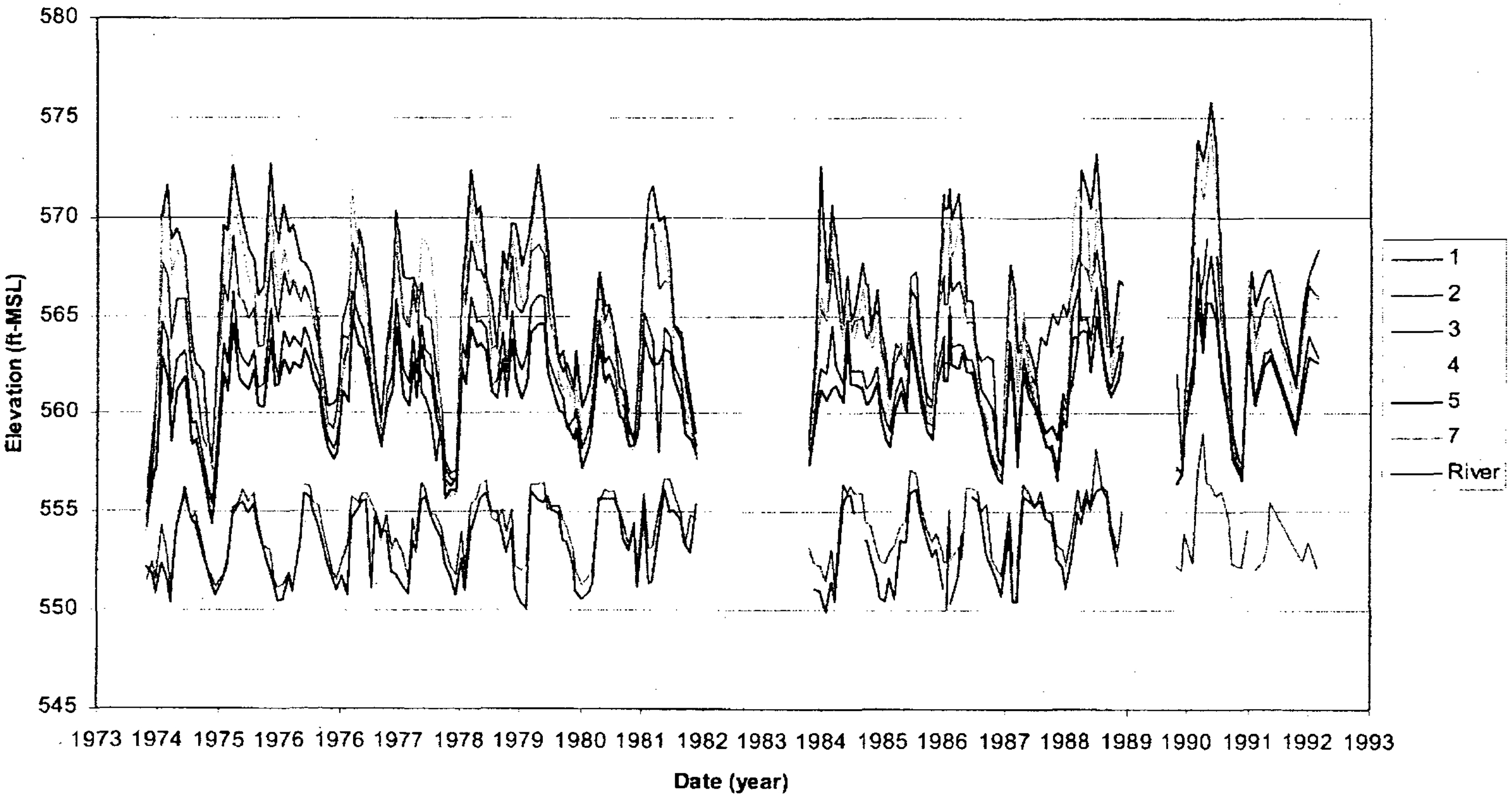


Figure 3.3. Time Series Groundwater Levels at Regional Site Wells (1974 – 1992)

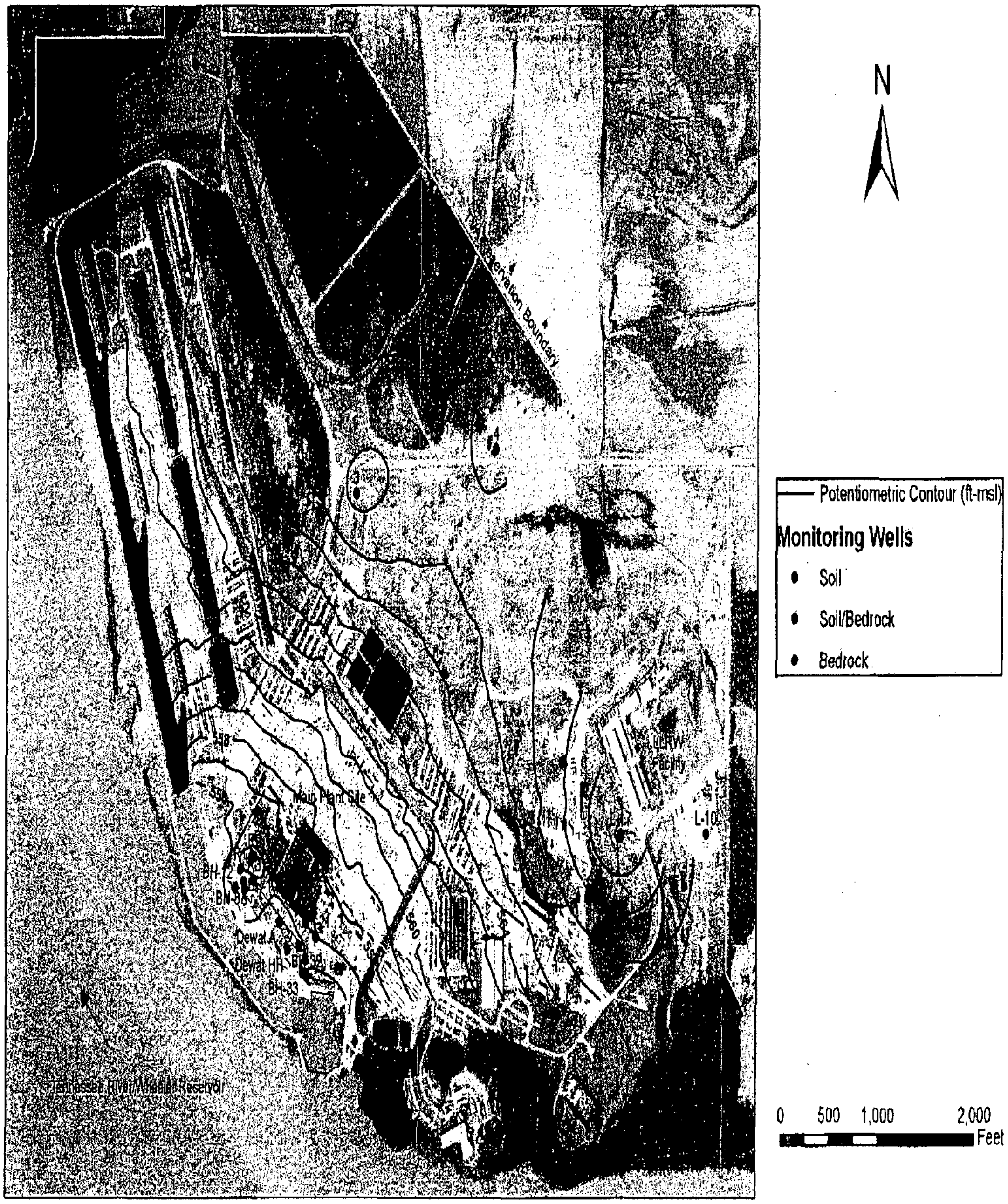


Figure 3.4 Map Showing Historical Site Wells

Within overburden soils at the site, groundwater movement is generally downward. Local areas of natural lateral flow likely occur near some streams, topographic lows, and where extensive root systems exist. Anomalous groundwater movement might also occur in areas that have experienced soil unraveling and in the vicinities of pipelines (especially those with relatively permeable bedding and fill). Based on 15 undisturbed soil samples, Boggs (1982) determined that the saturated hydraulic conductivity of site soils in the vicinity of the LLRW storage facility averages 1.1E-06 ft/s. Singleton (1981) collected three undisturbed residual clay soil samples in the area of the Unit 3 RHR tunnels (south of the reactor building). Lab permeameter results indicated horizontal hydraulic conductivity values ranging from 2.75E-07 to 2.65E-08 cm/s and vertical hydraulic conductivity values ranging from 1.79E-07 to 3.11E-08 cm/s. Based on subsurface investigations of the Tuscumbia-Fort Payne in Muscle Shoals, Alabama, Julian et al. (1993) indicates that the chert gravel horizon (weathered zone) near the top of bedrock is relatively transmissive compared to residual soils, allowing lateral groundwater movement. Observations of groundwater levels during early site borings (TVA, 1972) suggest that groundwater within the cherty gravel zone at the top of bedrock might be semi-confined.

The Tuscumbia-Fort Payne aquifer system underlies BFN. It is the most important water-bearing unit in the site vicinity from a regional perspective since it is a source of water for both wells and springs in the area. Groundwater flow in the Tuscumbia Limestone occurs exclusively in fractured and weathered zones. The orientation of fractures and solution features within the Tuscumbia is coincident with a structurally controlled joint system (i.e., along strike and dip). Studies by Julian et al. (1993) indicate that the transmissivities of bedrock fractures and solution features may decrease with depth. Although fractured, the silty, siliceous nature of the Fort Payne chert inhibits the development of solution features. Therefore, the average permeability of the Fort Payne at the site is expected to be less than that of the Tuscumbia limestone.

The Tuscumbia-Fort Payne aquifer system provides volumes of water sufficient for domestic supplies and some municipal and industrial supplies in the region. Groundwater associated with this aquifer system is a calcium-bicarbonate type and can generally be used without extensive treatment. Groundwater supplies within a 50-mile radius of BFN were previously identified by TVA (1972). An off-site well survey was conducted in May 1995 to identify groundwater supplies within a two-mile radius of the BFN site and this information is provided by TVA (1999). The closest known public groundwater supply (Limestone County Water System, Well G-1) resides approximately two-miles north of BFN (ADEM, 2001). There is no groundwater use by BFN and site dewatering wells have been inactive since about 1984. All wells at the site are used for environmental monitoring purposes only.

3.4 Hydrology

BFN is located near Tennessee River Mile (TRM) 294 on Wheeler Reservoir. The drainage area of the Tennessee River watershed at this location is 27,130 mi^2. Guntersville Dam, 55 miles upstream, has a drainage area of 24,450 mi^2. Wheeler Dam is located downstream of BFN and its headwaters affect flood elevations at the site.

Local drainage across the site can be subdivided into four main areas: (1) a small unnamed stream (a portion of which has been relocated) drains a 1.35 mi^2 area northwest of the plant, (2) the plant area (100 acres) just north of the 500 kV switchyard discharges to the switchyard drainage channel, (3) the main plant area discharges to the channel via a system of catch basins and stormwater pipelines, and (4) the area draining to the cooling tower system of channels. Figure 3.5 shows current plant topography with generalized direction of runoff indicated by arrows.

The characteristics of various site infrastructure components can have a significant impact on groundwater movement. The plant water control channels, for instance, serve as downgradient hydraulic boundaries. Major plant impoundments such as the wastewater lagoons can influence shallow groundwater flow by generating a mounding effect in the local surrounding area. Underground piping and associated excavation and backfill from construction also influence groundwater movement by providing preferential flow regimes via relatively transmissive backfill surrounding the pipelines. The coupled size and extent of some of these appurtenances (e.g., primary water intake and discharge lines) can produce local hydraulic boundaries at the scale of the plant site.

3.5 Other Relevant Studies

3.5.1 CCW Intake Conduit Investigations

Cooling water is pumped to the turbine building by nine intake pumps (3 per unit) located at the intake pumping station (Figure 1.1). Discharge from the intake pumps is conveyed to a unit's condenser via a 16.5-ft concrete intake conduit (one per unit) at an approximate flow rate of 660,000 gpm.

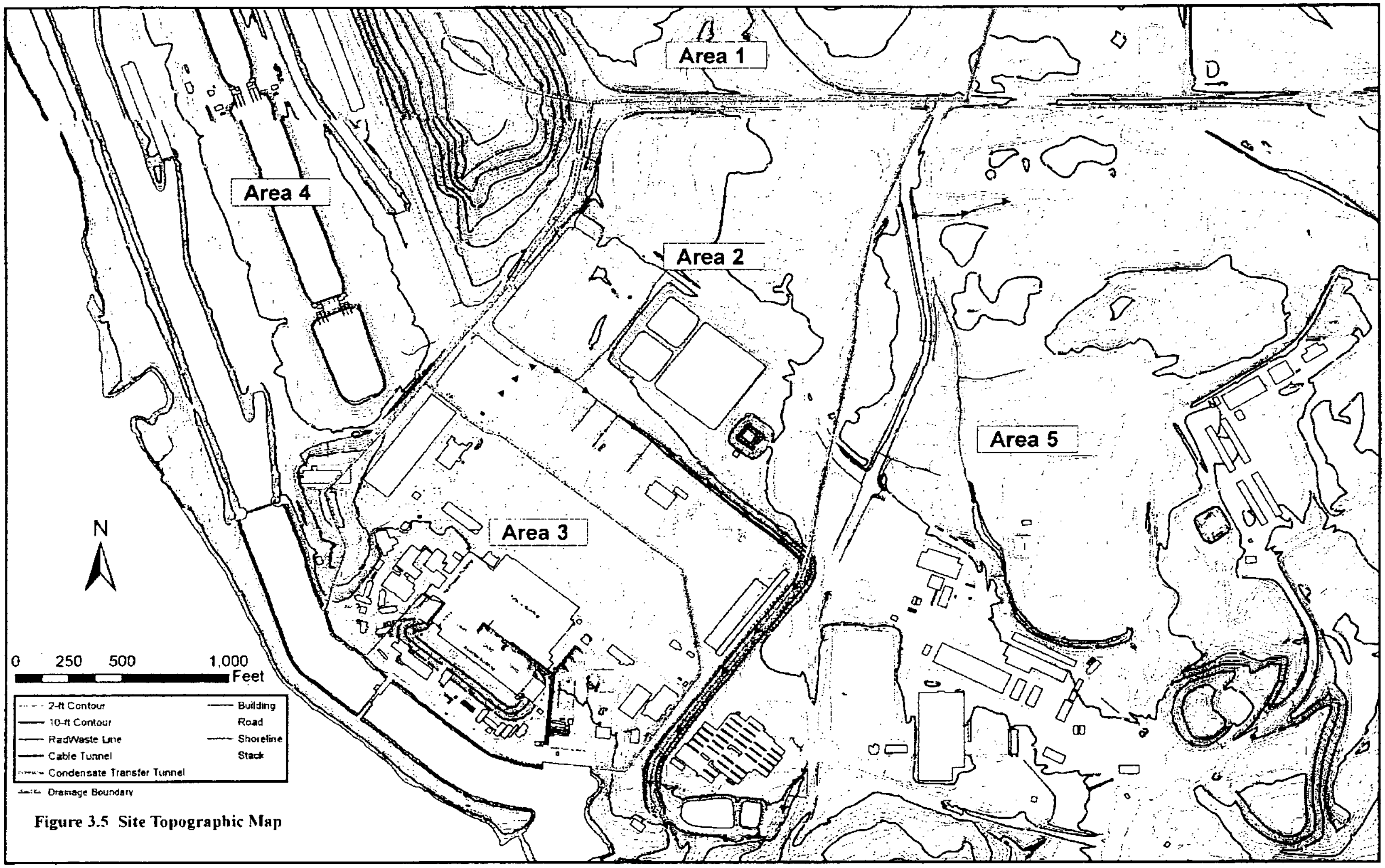


Figure 3.5 Site Topographic Map

Tracer Test Investigating Leakage from Unit One Intake Conduit at BFN - February 13, 1979 (Ungate et al., 1979)

A tracer test performed during February 1979 showed that water was leaking from the Unit 1 intake conduit. Water was discharging to ground surface in an area about 300 ft north of the intake pumping station at a rate of 5-10 gpm. Rhodamine WT dye was injected at the Unit 1 conduit intake and continuous monitoring was conducted in five shallow (2-ft deep) observation holes. The travel time of the tracer from the leak through at least 10 feet of overburden to ground surface was only about two minutes. Ungate et al. (1979) concluded that the leakage rate from the conduit(s) was resulting in high groundwater travel velocities and that the estimated 5-10 gpm discharge rate was likely low.

Tracer Test to Investigate Leakage from Unit One Intake Conduit at BFN - December 3 and 4, 1980 (Herren, 1980)

This dye trace was a follow-up of that performed in February 1979 (Ungate et al., 1979). Water was continuing to flow from the ground and from a crack in a concrete trough carrying conduits of various sizes (just south of the No.1 Condensate Storage Tank near the nitrogen tank). The observed flow rate of water from the ground was 5-16 gal/min; however, it was estimated that the leakage rate from the conduit is higher. Rhodamine WT dye was injected at the Unit 1 conduit intake and continuous monitoring was conducted in one shallow observation hole and at the crack. The travel time from the leak through at least 10 feet of overburden to ground surface was about three minutes.

Tracer Test to Investigate Leakage from Units One, Two, and Three Intake Conduits at BFN - January 27-29, 1981 (Herren, 1981)

Previous investigations (Ungate et al., 1979; Herren, 1980) revealed that the Unit 1 intake conduit was leaking in the immediate vicinity of the nitrogen tank. Water flow from the ground and from a crack in a concrete trough was observed. Since the 1980 investigation, another leak developed in the roadway approximately 125 feet south of the nitrogen tank over the Unit 1 intake conduit and a sinkhole formed in the ground surface on the south side of the No. 1 Condensate Storage Tank, which was under construction. The hole was approximately 10 feet in diameter, 7 feet deep, and contained a pool of water 2.5 feet deep.

Rhodamine WT dye was injected at three different times for each at the unit intake conduits. Results of the dye trace for the Unit 1 intake conduit revealed that the surface water flows, the flows of water in the concrete trough, and the flows in the roadway were originating from the Unit 1 intake conduit. No tracer dye was detected in the sinkhole. A dye trace test for Unit 2 intake conduit indicated that it was leaking and contributing approximately 20 - 25 gpm of water into the sinkhole and 3 - 4 gpm to a storm drain near the condensate tank. No leakage was observed from the Unit 3 intake conduit based on dye tracing.

3.5.2 Inleakage and Settlement Reports

Groundwater dewatering at BFN was initially conducted to support construction activities (e.g., maintain reasonably dry foundation conditions). The reactor building is situated relatively deep compared to most other structures at the site; hence, the deeper excavations required groundwater dewatering. Examination of construction photos for the BFN site indicates that a dewatering station was situated at the SE corner of the reactor building as early as 1969. Plant construction progressed from Unit 1 through Unit 3 and chronologically upward. The dewatering station remained in place throughout this entire period; and, as backfill was added around lower structures, riser pipe was apparently added so that the dewatering pump(s) could remain at basal elevations. Hence, the current locations of the inactive dewatering wells are an artifact of construction dewatering. TVA design drawing 17W305-3 shows that the dewatering pump suction was located in crushed stone, and progress photos of dewatering system construction show a coarse stone being used as fill in the area of the pump suction. Such conditions promote soil unraveling and movement of fine-grained soils to the pump suction.

In 1980, the TVA Engineering Design group identified settlement problems associated with soils and soil-supported structures at BFN. An investigative program was initiated in September 1980 to determine the causes of these problems, potential effects on plant structures and appurtenances, and the necessity for any type of corrective action. Three interim reports related to the settlement and soil unraveling were issued by TVA from 1980-81 (TVA, 1980, 1981a, and 1981b). A fourth report was issued in 1984 (TVA, 1984).

Files from the TVA Engineering Laboratory show the results of potentiometric mapping during dewatering operations in 1981 based on eight monitoring wells. Two of these wells were situated near the reactor building and the remainder was located along the channel. Dye tracing in conjunction with this study indicated rapid groundwater transport (on the order of several hundred feet per day). Total suspended solids (TSS) measurements of well discharge water began during this investigation.

TVA (1984) identified significant settlement in the Unit 3 RHR-Essential Equipment Cooling Water (EECW) tunnel and a rotation of the Unit 3 vent vault toward the reactor building. TVA design drawing 17W305-3 shows that the dewatering pump suction was located in crushed stone, and progress photos of dewatering system construction show a coarse stone being used as fill in the area of the pump suction. Such conditions promote soil unraveling and movement of fine-grained soils to the pump suction. Based on TSS measurements of well discharge water, TVA (1984) estimated that 16 – 430 yd^3 of soil could have been pirated from the subsurface each year during dewatering. (b)(4),(b)(5)

(b)(4),(b)(5)

4.0 Tritium Investigation

As previously mentioned, field investigations during this study were primarily directed towards two locations at the main plant site. The first location is proximal to the cable tunnel which extends from the intake pumping station to the turbine building (see Section 2.2.2). The second location is an area associated with the radwaste discharge lines which are located beneath the service bay on the northwest side of the reactor building (see Section 2.1.2). Major tasks associated with field investigations included:

1. Redevelopment and sampling of regional bedrock wells 1 – 5
2. Manual sampling of accessible yard drain catch basins, vaults, and manholes
3. Groundwater sampling using Geoprobe methods
4. Completion of selected Geoprobe boreholes as monitoring wells
5. Water level monitoring

4.1 Redevelopment and Sampling of Wells 1 - 5

Regional bedrock wells 1-5 (Figure 1.2) were redeveloped by TVA field personnel during the interval March 6 - 8, 2006 using a combination of over-pumping and backwashing techniques. Groundwater samples were collected on March 10, 2006, using disposable Teflon bailers and transferred to 100 mL wide-mouth plastic sample containers. Samples were packaged in coolers and transmitted to TVA's Western Area Radiological Laboratory (WARL) for tritium analysis. Laboratory analytical results indicated that tritium concentrations were less than the minimum detection concentration (MDC) of 220 pCi/L. The 6-inch ID wellheads at these locations were subsequently reconditioned with locking compression caps and protective balusters were installed.

4.2 Manual Sampling of Yard Drains, Vaults, and Manholes

Manual sampling of yard drain catch basins, vaults, and manholes (MHs) was conducted at 16 locations (Figure 4.1) during March and April 2006. Sampling locations were initially identified using the following criteria: availability of water, depth (i.e., deep storm drain catch basins), accessibility, and proximity to the radwaste lines and cable tunnel. Subsequent samples were collected during Geoprobe boring work based on observations of water in MHs and vaults. Sampling was performed by TVA personnel using disposable Teflon bailers or wide-mouth sampling containers affixed to extension rods. Samples were transferred to 100 mL wide-mouth plastic sample containers, packaged in coolers, and transmitted to the WARL for tritium analysis.

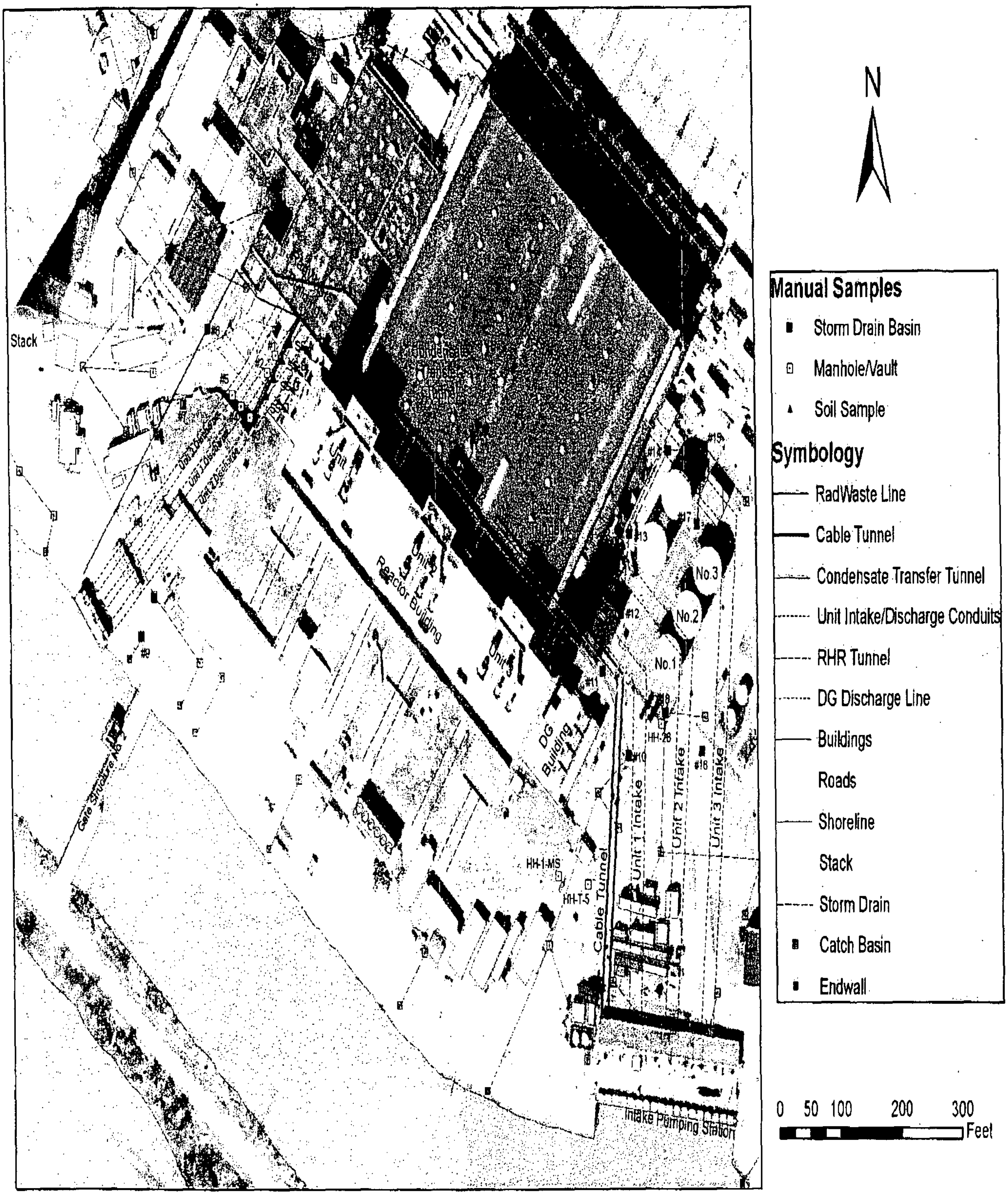


Figure 4.1. Site Map Showing Manual Sampling Locations

Table 4.1 provides a summary of sampling locations and analytical results. Tritium was initially (3/21/2006 sampling) observed at concentrations of 516.8 and 279.2 pCi/L, respectively, in MH-318 and MH-319 (Figure 4.1). Subsequent samples from these MHs (4/25/2006) indicated that tritium was less than the MDC of 222.9 pCi/L. Two shallow (4.6-ft deep) electrical vaults (HH-1-MS and HH-T-5) exhibited low concentrations of tritium (<380 pCi/L). All other sample results were less than MDCs. Observation of tritium in the electrical vaults is currently inexplicable.

Soil samples were collected at four locations in the western service bay (Figure 4.1) in May 2006 to support potential excavation and replacement of underground lines. Soil samples were collected from ground surface to a depth of 2.5 ft at each location. Analytical results indicated that tritium in all shallow soil samples was < MDC.

4.3 Geoprobe Sampling

In evaluating possible methods for groundwater sampling at the site, a direct-push device was selected since it allows tools to be "pushed" into the ground without the use of drilling to remove soil or to make a path for the tool. A Geoprobe direct-push machine relies on a relatively small amount of static (vehicle) weight combined with percussion as the energy for advancement of a tool string. The Geoprobe offers a significant safety advantage since the probe tends to resists on concrete and steel pipelines, and down-hole tools are easily decontaminated between borings.

Thirty-four (34) Geoprobe boring locations were initially identified at the site based on the existing knowledge of groundwater movement and relative locations of major underground lines and appurtenances (e.g. cable tunnel, intake and discharge lines, etc.) since bedding material might allow privileged migration of groundwater contaminants. The proposed boring locations were then transferred to an orthophoto map of the site. This was followed by a review of site design and as-built drawings to more accurately identify underground utilities in the immediate vicinities of proposed boring locations and field-staking of the borings. For final verification of proposed boring locations, a Ground Penetrating Radar (GPR) investigation was conducted under contract with MACTEC (2006). The GPR survey evaluated potential subsurface obstructions within a 10-ft radius of the field-staked boring locations. The boring locations were offset if direct obstructions were identified to provide a minimum horizontal clearance of 2-ft in all directions.

Table 4.1 Summary of Tritium Results from Manual Sampling Phase

					AL West NAD27 (ft)			
Location	Type	Top of Ground (ft-msl)	Depth (ft)	Invert Ele (ft-msl)	Easting	Northing	Sampling Date	Tritium Concentration (pCI/L)
#1	MH-318	564.8	6.8	558.0	614275.4	1711514.4	3/21/2006	**516.8**
#2	MH-319	564.8	7.1	557.7	614261.9	1711497.1	3/21/2006	**279.2**
#1	MH-318	564.8	6.8	558.0	614275.4	1711514.4	4/25/2006	<222.9
#2	MH-319	564.8	7.1	557.7	614261.9	1711497.1	4/25/2006	<222.9
#3	Vault	564.9	4.0	560.9	614232.4	1711452.9	3/21/2006	dry
#4	Vault	564.6	4.0	560.6	614217.8	1711464.0	3/21/2006	dry
#5	Vault	564.4	4.3	560.1	614203.4	1711475.4	3/21/2006	dry
#6	MH	569.8	11.3	558.5	614163.0	1711540.4	3/21/2006	<218
#7	Yard Drain	569.0	9.5	559.5	614121.7	1711466.6	3/21/2006	<218
#8	Yard Drain	561.9	16.0	553.4	614069.3	1711274.4	3/21/2006	<218
#9	Yard Drain	563.8	5.0	558.8	614042.2	1711247.4	3/21/2006	<218
#10	Yard Drain	569.8	12.0	557.8	614855.7	1711127.8	3/22/2006	<218
#11	Yard Drain	575.9	10.0	565.9	614815.3	1711213.0	3/22/2006	<218
#12	Yard Drain	575.6	8.0	567.6	614839.9	1711259.6	3/22/2006	<218
#13	Yard Drain	575.6	8.0	567.6	614854.7	1711338.8	3/22/2006	<218
#14	Yard Drain	574.9	8.0	566.9	614918.5	1711420.7	3/22/2006	<218
#15	Yard Drain	575.9	8.0	567.9	614993.8	1711426.2	3/22/2006	<218
#16	Yard Drain	571.6	4.0	567.6	614970.4	1711124.7	3/22/2006	<218
#17	Yard Drain	na	na	na	614964.4	1711350.1	3/17/2006	<218
#18	Yard Drain	na	na	na	614930.0	1711167.5	3/17/2006	dry
HH-1-MS	Electrical Vault	567.2	4.6	562.6	614732.1	1711003.0	4/20/2006	**367**
HH-T-5	Electrical Vault	566.5	4.6	561.9	614780.7	1710994.7	4/24/2006	**375**
HH-26	Electrical Vault	571.2	4.6	566.6	614903.8	1711151.2	4/24/2006	dry
SS-A	Soil Sample	565.0	2.5	562.5	614299.6	1711527.4	May-06	< MDC
SS-B	Soil Sample	564.9	2.5	562.4	614286.6	1711510.4	May-06	< MDC
SS-C	Soil Sample	565.0	2.5	562.5	614272.6	1711493.0	May-06	< MDC
SS-D	Soil Sample	564.9	2.5	562.4	614258.9	1711475.9	May-06	< MDC

Sampling of groundwater using Geoprobe methods was conducted by TVA personnel at 29 borehole locations during April and May 2006 (Figure 4.2). Two existing monitoring wells (Dewat A and Dewat HH) and an inactive dewatering well (Dewat E) were also located and sampled during this period. Existing Geoprobe wells R1, R2, and R3 were also sampled during this phase of investigation. The primary Geoprobe used for boring was a truck-mounted model 5400 unit. Two borings (BH-10 and BH-37) were advanced using an ATV-mounted Geoprobe unit due to accessibility constraints (ground surface slopes).

When possible, groundwater samples were collected in situ (from within the Geoprobe push-rod at depth) using a 0.5-inch OD stainless steel bailer. Samples were also collected directly from the borehole (after extraction of the Geoprobe push-rod) using disposable Teflon bailers or a 0.5-inch OD stainless steel bailer. For holes where groundwater recovery was slow, temporary 0.5-inch ID screen and casing were installed and samples were collected using a 0.5-inch OD stainless steel bailer. All temporary well materials and disposable bailers were discarded after a single use. Groundwater samples were transferred to 100 mL wide-mouth plastic sample containers, packaged in coolers, and transmitted to the WARL for tritium analysis. Decontamination involved scrubbing downhole equipment with a distilled water/laboratory detergent mix and rinsing with distilled water.

Figure 4.3 provides a profile of Geoprobe borings installed during this phase of the investigation. Eight of the Geoprobe borings were completed as 0.5-inch or 1-inch ID monitoring wells to supplement groundwater level measurements at the site. These wells include BH-8, BH-10, BH-12, BH-21, BH-30A, BH-30B, BH-32, and BH-33. One–inch ID wells were required where continuous down-hole data loggers were installed. Well diagrams are provided in Appendix A.

Table 4.2 provides a summary of groundwater sampling locations and analytical results from Geoprobe investigations. Tritium observations at wells Dewat A and E prompted the installation of additional borings (BH-30B, BH-37, and BH-38A, and BH-38B) since Dewat A and E are relatively deep wells extending to bedrock. In general, the highest tritium concentrations in the shallow groundwater system were associated with the eastern portion of the site.

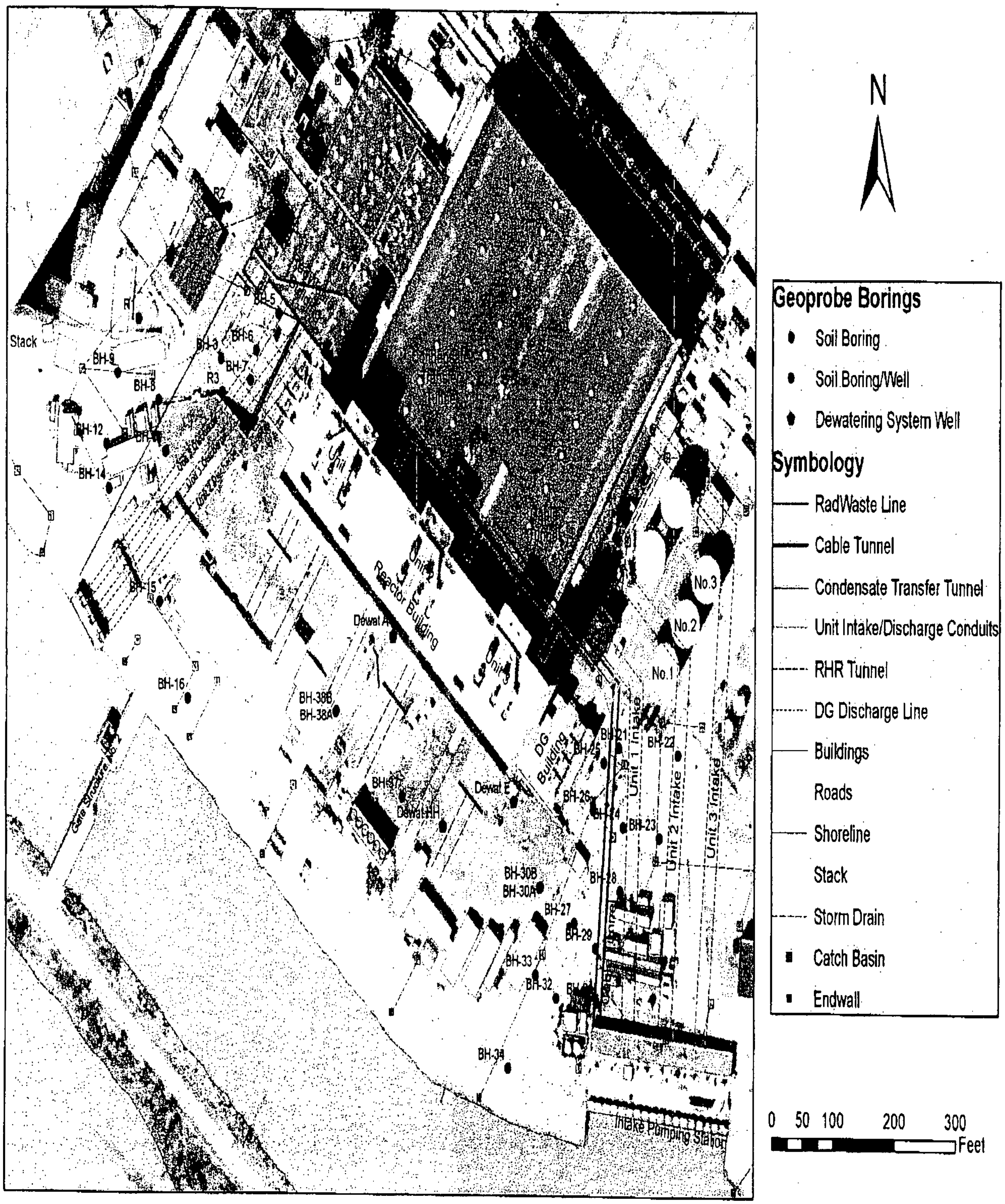


Figure 4.2. Site Map Showing Geoprobe Borings, Monitoring Wells, and Dewatering System Wells

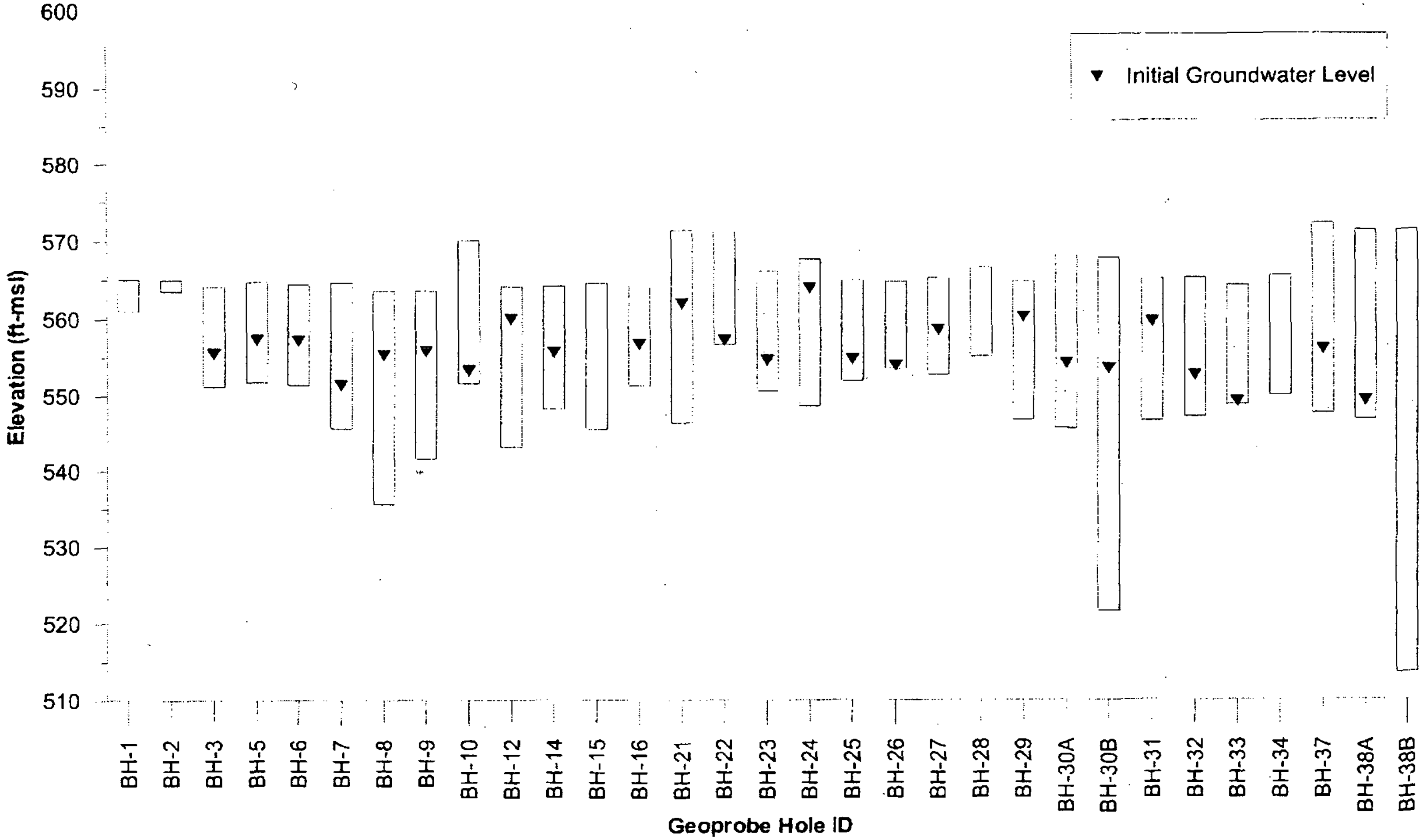


Figure 4.3 Profile of Geoprobe Borings

Table 4.2 Summary of Tritium Results from Geoprobe Sampling Phase

					AL West NAD27 (ft)			
Location	Type	Top of Ground (ft-msl)	Depth (ft)	Bottom of Hole (ft-msl)	Easting	Northing	Sampling Date	Tritium Concentration (pCi/L)
R1	Soil	563.0	14.5	548.5	614051.3	1711553.3	04/18/2006	<222.1
R2	Soil	566.5	23.5	543.0	614198.4	1711662.2	04/18/2006	<222.1
R3	Soil	563.7	17.4	546.3	614188.8	1711481.1	04/18/2006	<222.1
BH-3	Soil	564.1	13.0	551.1	614186.3	1711515.1	04/25/2006	<222.9
BH-5	Soil	564.7	13.0	551.7	614280.8	1711559.0	04/18/2006	<222.1
BH-6	Soil	564.3	13.0	551.3	614244.4	1711523.4	04/18/2006	<222.1
BH-7	Soil	564.6	19.0	545.6	614234.6	1711493.6	04/20/2006	<215.6
BH-8	Soil	563.5	28.0	535.5	614084.3	1711473.1	04/20/2006	<215.6
BH-9	Soil	563.5	22.0	541.5	614017.6	1711500.1	04/20/2006	<215.6
BH-10	Soil	569.9	18.5	551.4	614095.8	1711423.2	04/28/2006	<218.3
BH-12	Soil	564.1	21.0	543.1	613999.9	1711429.9	04/21/2006	<215.6
BH-14	Soil	564.0	16.0	548.0	614003.9	1711386.5	04/20/2006	<215.6
BH-15	Soil	564.4	19.0	545.4	614086.3	1711276.3	04/20/2006	<215.6
BH-16	Soil	564.1	13.0	551.1	614133.0	1711182.1	04/25/2006	<222.9
BH-21	Soil	571.2	25.0	546.2	614840.1	1711136.2	04/21/2006	<215.6
BH-22	Soil	571.0	14.5	556.5	614936.3	1711129.6	04/21/2006	<215.6
BH-23	Soil	565.9	15.5	550.4	614906.7	1711047.9	04/24/2006	<276.5
BH-24	Soil	567.5	19.0	548.5	614848.0	1711057.7	04/20/2006	<215.6
BH-25	Soil	564.7	13.0	551.7	614816.0	1711121.6	04/20/2006	**4,325**
BH-26	Soil	564.6	11.3	553.3	614798.7	1711075.0	04/21/2006	<215.6
BH-27	Soil	565.0	12.5	552.5	614768.4	1710965.3	04/26/2006	<222.9
BH-28	Soil	566.3	11.5	554.8	614843.2	1710996.1	04/24/2006	<276.5
BH-29	Soil	564.5	18.0	546.5	614803.0	1710940.8	04/24/2006	<222.9
BH-30A	Soil	567.9	22.5	545.4	614711.0	1710999.3	04/24/2006	<276.5
BH 30B	Soil	567.5	46.0	521.5	614713.0	1710999.7	05/03/2006	<266.5
BH-31	Soil	564.9	18.5	546.4	614805.2	1710888.0	04/25/2006	<222.9
BH-32	Soil	564.9	18.0	546.9	614738.8	1710891.9	04/26/2006	<222.9
BH-33	Soil	564.0	15.5	548.5	614704.9	1710914.5	04/25/2006	<222.9
BH-34	Soil	565.2	15.5	549.7	614660.3	1710822.0	04/26/2006	<222.9
BH 37	Soil	571.9	24.5	547.4	614485.2	1711086.1	05/02/2006	**335.1**
BH 38A	Soil	571.0	24.5	546.5	614377.0	1711171.4	05/02/2006	**344.7**
BH 38B	Soil	571.0	57.5	513.5	614376.0	1711170.0	05/03/2006	**626.8**
Dewat A	Soil	594.4	80.4	514.0	614469.0	1711244.8	04/18/2006	**1,020.9**
Dewat E	Soil	592.5	75.6	518.5	614668.1	1711082.3	04/18/2006	**1,324.1**
Dewat HH	Soil	578.3	29.2	552.4	614552.7	1711057.6	05/02/2006	<266.5

4.4 Water Level Monitoring

Groundwater level monitoring at the site included manual measurements at existing and new wells in close proximity to the plant site on a biweekly basis beginning on April 28, 2006. Continuous water level and temperature monitoring was conducted at five selected wells and for the surface water channel on either side of Gate Structure No. 2 (Figure 4.4). Solinst (model 3001) downhole dataloggers were deployed for continuous monitoring.

Figure 4.4 depicts the potentiometric surface at the site from May 25, 2006, water level measurements. Results indicate that that groundwater movement is generally W-SW toward the channel/river. Hydraulic gradients are gentle (~0.006 ft/ft) on the eastern portion of the site. Groundwater mounding is evident in the vicinity of BH-10 and BH-12 on the western portion of the site. Generally, such conditions are associated with leaking underground water lines in the immediate vicinity of the observation wells. As shown in Figure 4.5, groundwater levels at BH-12 are highly variable relative to all site wells and the channel which serves as a hydraulic boundary to the west. Groundwater levels at BH-10 also exhibit similar variability but are less pronounced than at BH-12. The two larger groundwater level increases at BH-10 correlate with similar significant changes at BH-12. Water temperatures in the unit discharge lines are generally on the order of 35 – 40°C; hence, leakage may be associated with other water lines (e.g., EECW lines) in the area.

It is interesting to note that continuous groundwater level measurements at well Dewat A correlate exceedingly well with surface water level measurements in the channel (primarily the east side of the channel). Although well Dewat A is positioned approximately 300 ft from the channel, it is developed within the weathered zone at the top of bedrock. These results suggest that the deeper groundwater flow zone at the top of bedrock is relatively transmissive compared to the shallow soil horizon.

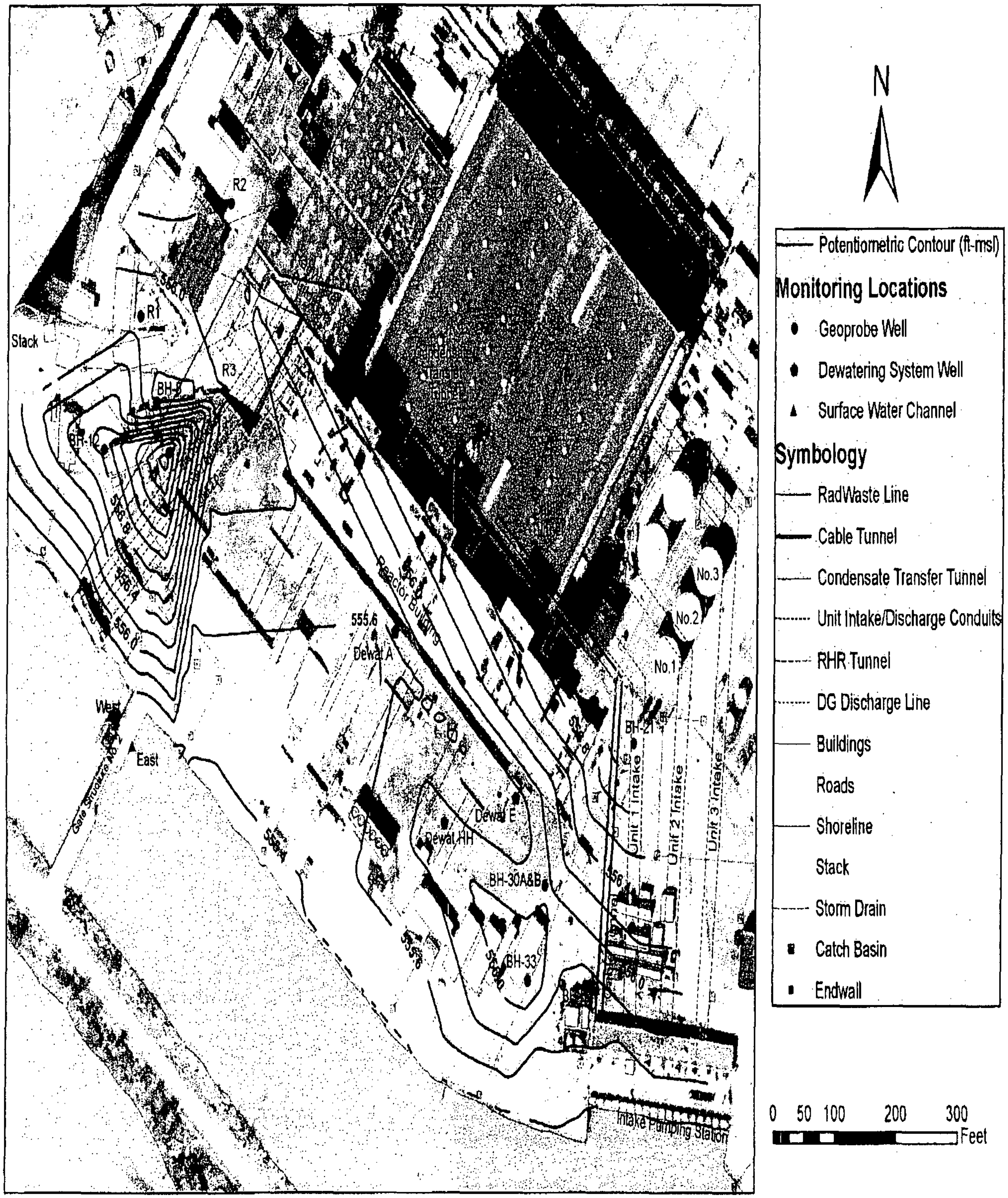


Figure 4.4. Potentiometric Surface Based on May 25, 2006 Water Level Measurements

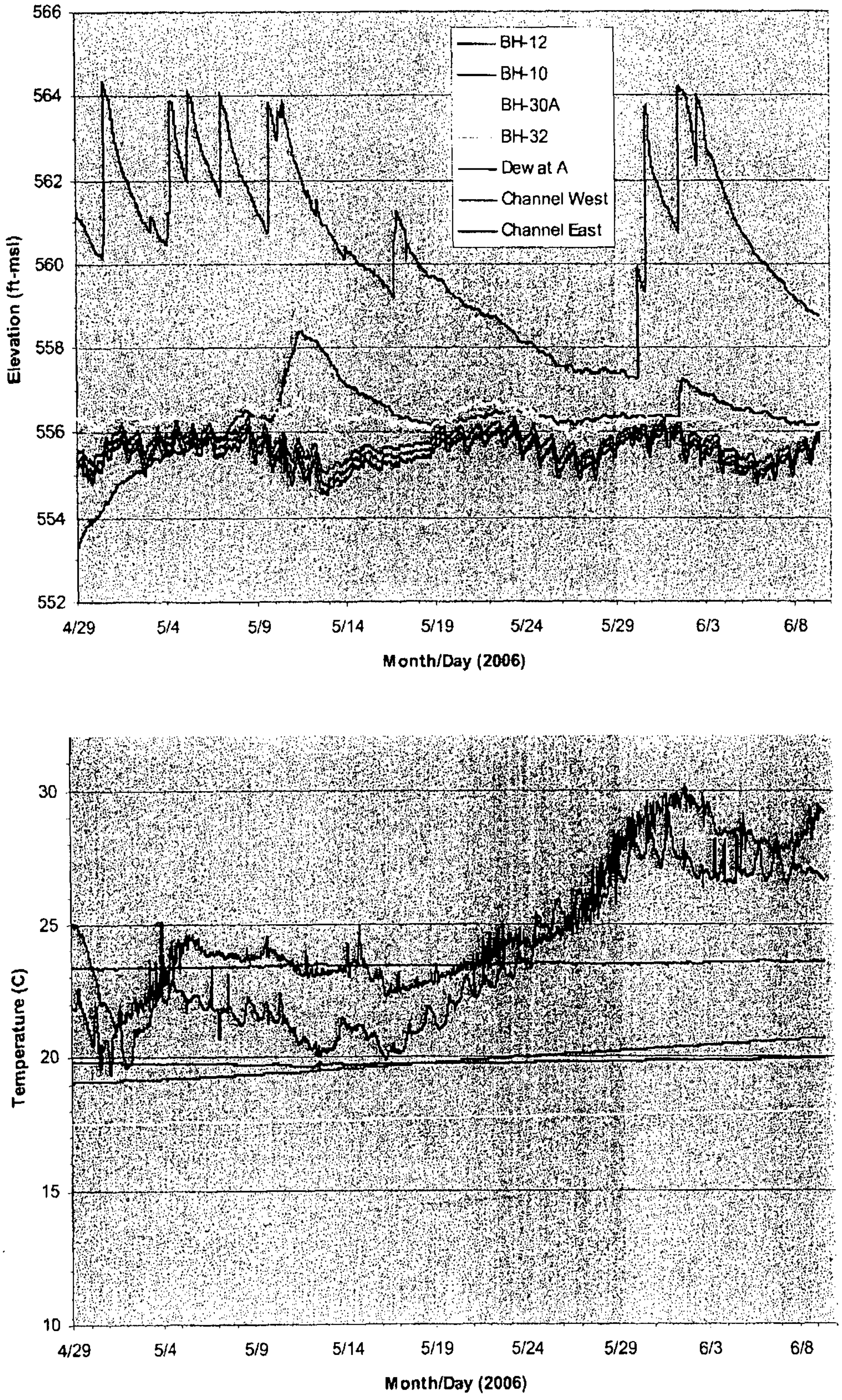


Figure 4.5. Time-Series Plot of Continuous Water Levels and Temperatures

5.0 Results and Recommendations

5.1 Tritium Distribution

Manual sampling at 16 locations (catch basins, manholes, and vaults) showed the positive detection of tritium within only four shallow manholes. Tritium was initially observed at concentrations of 516.8 and 279.2 pCi/L, respectively, in MH-318 and MH-319 (Figure 4.1; sampling IDs #1 and #2). Subsequent samples from these manholes indicated that tritium was less than the MDC of 222.9 pCi/L. Two shallow (4.6-ft deep) electrical vaults (HH-1-MS and HH-T-5) exhibited low concentrations of tritium (<380 pCi/L). Tritium observed at MH-318 and MH-319 is likely associated with the same source as that of REMP well R3. Observation of tritium in electrical vaults HH-1-MS and HH-T-5 is not completely explicable. The vaults possess impermeable covers and the groundwater table resides several feet below the vault bottoms. It is conceivable that the source of tritiated water within the vaults is associated with contaminated groundwater some distance upgradient (N-NW) of the electrical vaults. Electrical conduits (and their bedding materials) intersecting the vaults are probable avenues for groundwater transport into the vaults.

Groundwater sampling at 29 Geoprobe borings showed the positive detection of tritium at only six of these locations with the highest measured groundwater concentration (4,325 pCi/L) being observed at BH-25 (Figure 4.2; Table 4.2). Figure 5.1 shows the distribution of tritium based on groundwater sampling during this study. In general, the highest tritium concentrations in the shallow groundwater system are associated with the eastern portion of the site. Although data is sparse for the deeper flow regime (i.e., weathered zone and shallow bedrock), the extent of the tritium plume is reasonably bounded by sampling locations in the horizontal.

5.2 Tritium Source

The current results suggest that the source of tritiated groundwater is associated with the condensate transfer tunnel. Considering that the condensate transfer tunnel is of concrete construction with numerous expansion joints, water that might have been released into the tunnel could have found egress via the expansion joints and/or cracks through the tunnel wall. The vertical relationship of the cable and condensate transfer tunnels is depicted in a SW-NE profile of the plant (Figure 5.2). As described in Section 2, the cable tunnel and condensate transfer tunnel share a common concrete wall (Figure 2.3 and 2.4) along the majority of the transfer tunnel length. Tritiated water observed in the cable tunnel could have been transported directly through this mutual wall, or could have originated from contaminated groundwater in the immediate vicinity of the cable tunnel. The BFN staff is currently investigating historical water release(s) that might have occurred within the condensate transfer tunnel.

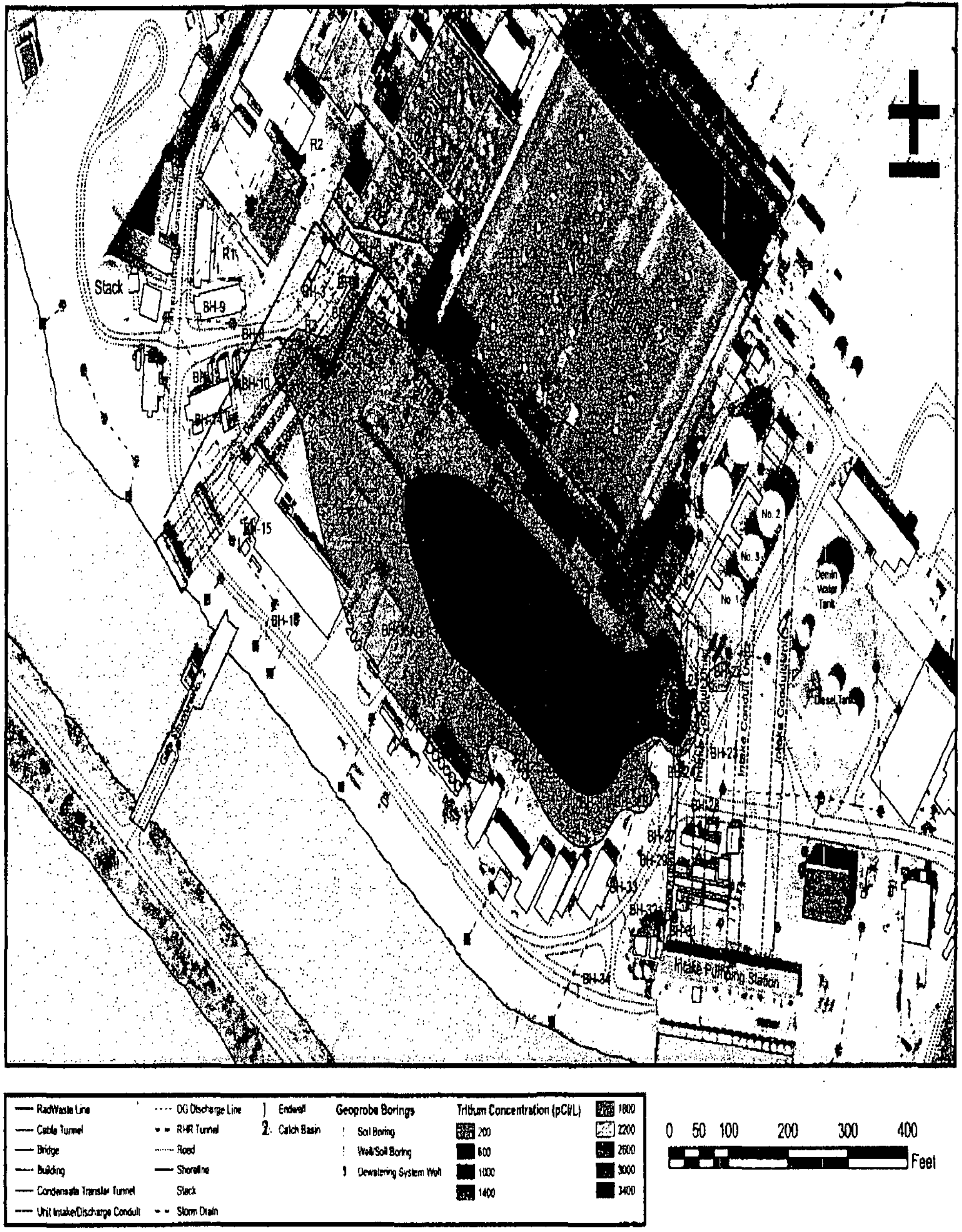


Figure 5.1 Site Map Showing Tritium Plume

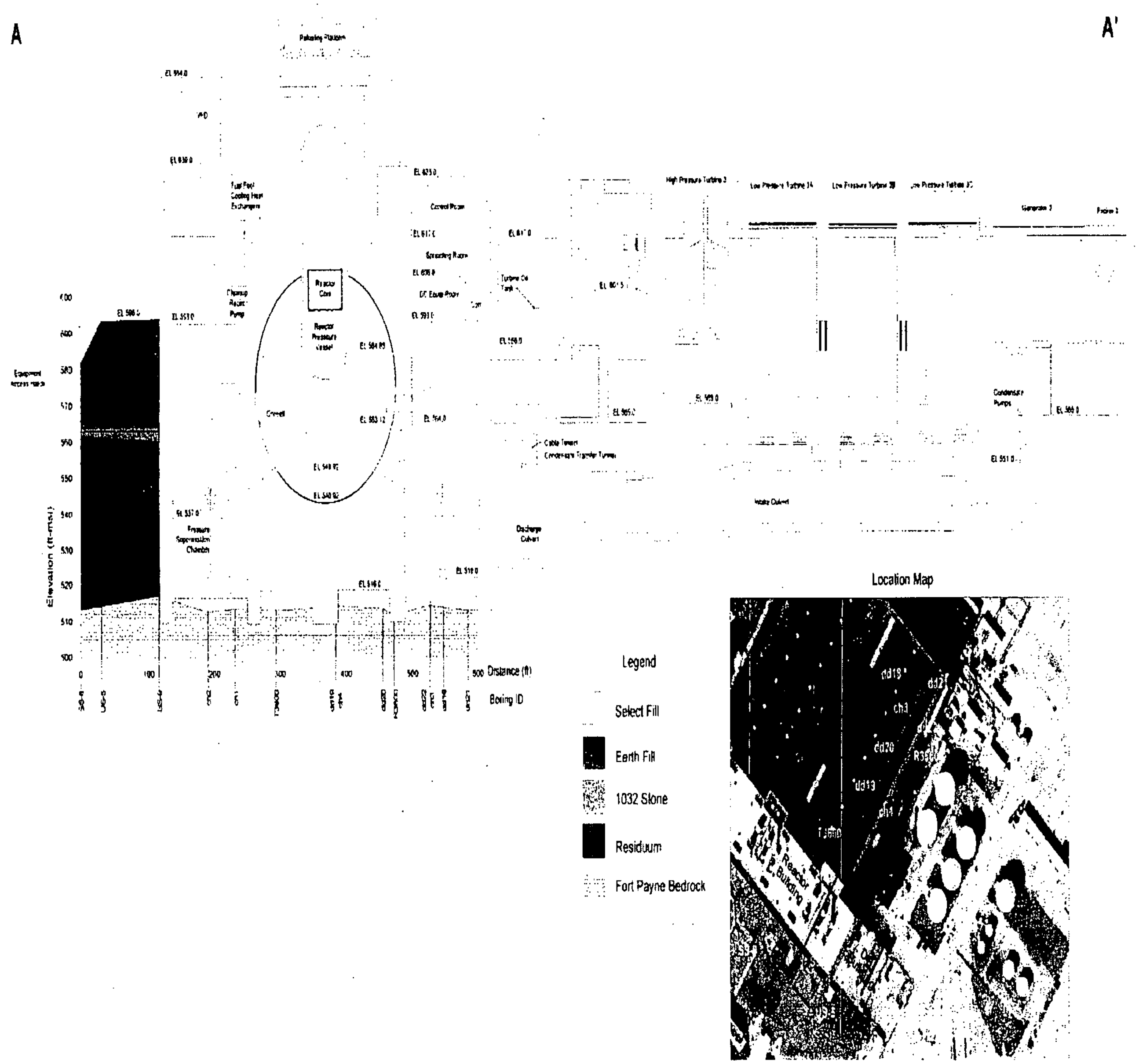


Figure 5.2. Southwest - Northeast Cross-Section through Reactor and Turbine Building

5.3 Tritium Transport and Fate

Tritium is a conservative contaminant – it is not susceptible to attenuation via sorption or biochemical degradation. Reduction of tritium concentrations in the groundwater system at BFN will occur primarily by hydrodynamic dispersion and dilution. The dispersion process is related to variations in groundwater velocity that occur on a microscale by differences in media porosity and on a macroscale by variations in hydraulic conductivity. Dispersion will result in reductions of tritium concentrations with increasing distance from the source (e.g., the condensate transfer tunnel). Dispersion will be more pronounced in the soil horizon relative to the deeper and more transmissive weathered bedrock horizon. However, the fate and transport of tritium in the site groundwater system is also likely to be governed by avenues of relatively rapid groundwater movement that exist within bedding material of larger pipelines and tunnels, along zones associated with soil unraveling (see Section 3.4.2), and along the weathered bedrock horizon.

The Unit 1 intake conduit is likely to function as a boundary for groundwater transport on the east side of the tritium plume. This is illustrated in the Figure 5.3 profile of the cable and condensate transfer tunnels relative to the Unit 1 intake conduit. Groundwater and surface water level measurements during the study confirm that the channel will ultimately be recipient to tritiated groundwater discharge from the site. Assuming conservative hydraulic conductivity of 1E5 ft/s and a hydraulic gradient of 0.01 ft/ft, approximately 0.5 gpm of groundwater can be estimated to discharge into a 1,000-ft wide reach of the channel. If full mixing is assumed to occur and the water within the 1,000-ft reach of channel is displaced during a single day, a groundwater/channel water dilution ratio of about 1:20,000 can be estimated. Such estimates would result in immeasurable aqueous tritium concentrations in receiving waters. For instance, using the highest measured tritium concentration in groundwater (4,325 pCi/L) would result in an aqueous tritium concentration of 0.22 pCi/L in the channel. Actual dilution ratios in the channel and subsequently the Tennessee River are dependent on plant operation and river flow.

5.4 Recommendations

(b)(4),(b)(5)

(b)(4),(b)(5) The following recommendations are submitted based on findings of this investigation:

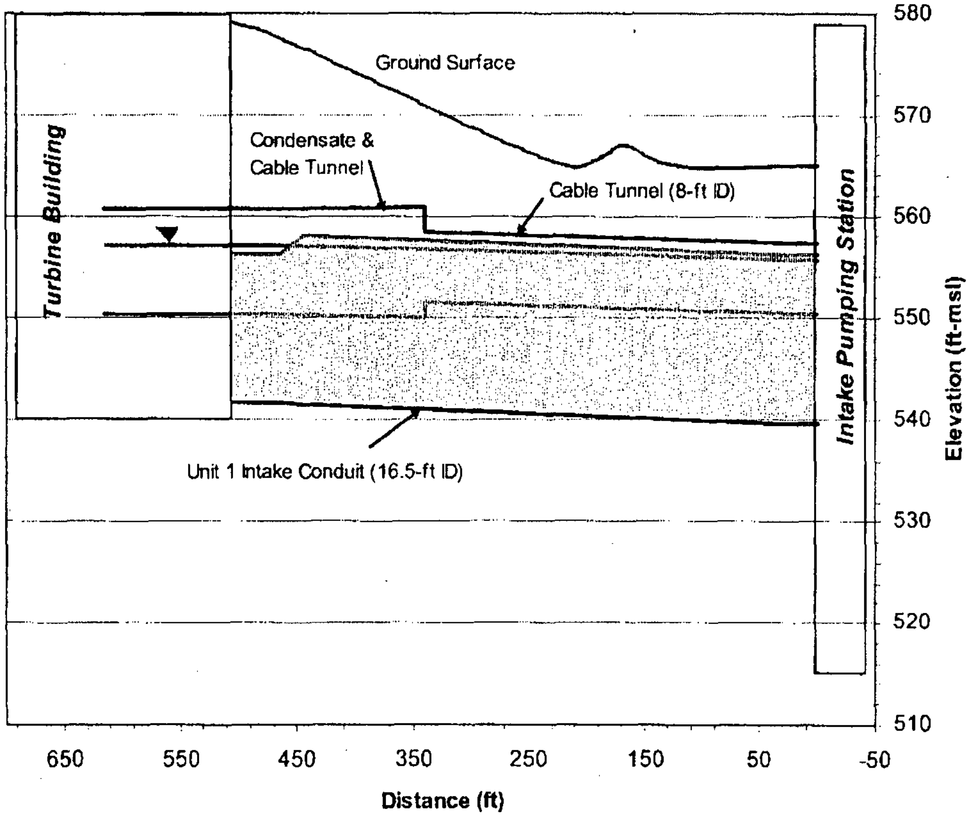


Figure 5.3. Profile Showing Vertical Relationship of Cable Tunnel, Condensate Transfer Tunnel, and Unit 1 Intake Conduit

1. *Source Term:* Spatial data and anecdotal evidence suggest that the condensate transfer tunnel is the most likely source of tritium at the site. (b)(4),(b)(5)

   (b)(4),(b)(5)

2. *Groundwater Monitoring:* (b)(4),(b)(5)

   (b)(4),(b)(5)

6.0 REFERENCES

ADEM, "Personal Communication with Enid Bittner, Alabama Department of Environment and Conservation, Public Groundwater Supplies Within a 2-Mile Radius of Browns Ferry Nuclear Plant," April 2001.

Boggs, J. Mark, "Browns Ferry Nuclear Plant Low-Level Radwaste Storage Facility Groundwater Pathway Analysis," Tennessee Valley Authority, Report No. WR28-1-67-116, October 1982.

Herren, Herman L., "Tracer Test to Investigate Leakage from Unit One Intake Conduit at the Browns Ferry Nuclear Plant December 3 and 4, 1980," Tennessee Valley Authority, Report No. WR28-2-67-109, December 1980.

Herren, Herman L., "Tracer Test to Investigate Leakage from Units One, Two and Three Intake Conduit at the Browns Ferry Nuclear Plant January 27-29, 1981," Tennessee Valley Authority, Report No. WR28-2-67-110, February 1981.

Julian, H. E., S. C. Young, C. Lu, and K. E. Richter, "NFERC Regional Groundwater Investigation," TVA Engineering Laboratory, Report No. WR28-1-520-191, Norris, Tennessee, April 1993.

MACTEC, "Ground Penetrating Radar Field Investigation Test Results, TVA Browns Ferry Nuclear Plant, Athens, Alabama," MACTEC Project 3043061020.01, April 2006.

TVA, "BFN Radiological Environmental Monitoring Program, Liquid Pathway Monitoring," TVA Western Area Radiological Laboratory, 2005.

TVA, "Browns Ferry Nuclear Plant - Final Safety Analysis Report," Tennessee Valley Authority, February 1972.

TVA, "Browns Ferry Nuclear Plant - Final Safety Analysis Report," Tennessee Valley Authority, 1999.

TVA, "Interim Report on Soil and Foundation Conditions," CEB81-46, September 1981b.

TVA, "Final Report on Soil and Foundation Conditions" CEB84-18, August 1984.

TVA, "Preliminary Evaluation of Sinkhole Formation and Raveling Failure at Browns Ferry Nuclear Plant," CEB81-21, June 1981a.

TVA, "Preliminary Evaluation of Vent Vault and RHR-EECW Tunnel Settlement at Browns Ferry Nuclear Plant," CEB80-70, December 1980.

Ungate, Christopher D., Dave A. McIntosh, and Herman L. Herren, "Tracer Test Investigating Leakage from Unit One Intake Conduit at the Browns Ferry Nuclear Plant February 13, 1979," Tennessee Valley Authority, Report No. WR28-2-67-103, March 1979.

Zurawski, A., "Summary Appraisals of the Nation's Ground-Water Resources - Tennessee Region", U.S. Geological Survey Professional Paper 813-L, 35 p. 1978.