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Report on the North Anna Early Site Permit Water Budget Model (LakeWBT) for Lake Anna

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1.0 Background

On September 25, 2003, the U.S. Nuclear Regulatory Commission (NRC) received an application from Dominion Nuclear North Anna, LLC (Dominion) for an early site permit (ESP). The site proposed is located within the existing North Anna Power Station (NAPS) site near Mineral, Virginia. The September 25, 2003, Environmental Report (ER) of this application was revised by letters dated October 2, 2003 (Revision 1), July 15, 2004 (Revision 2), and September 7, 2004 (Revision 3). Any reference in this technical report to the ER refers to Revision 3 (Dominion 2004), unless otherwise stated. Under the NRC regulations in Title 10 of the Code of Federal Regulations (CFR) Part 52 and in accordance with the applicable provisions of 10 CFR Part 51, which are the NRC regulations implementing the National Environmental Policy Act of 1969 (NEPA), NRC is required to prepare an environmental impact statement (EIS) as part of its review of an early site permit (ESP) application. A separate safety evaluation report will also be prepared in accordance with 10 CFR Part 52.

An ESP is a Commission approval of a site or sites for one or more nuclear power facilities. The filing of an application for an ESP is a process that is separate from the filing of an application for a construction permit (CP) or a combined license (COL) for such a facility. The ESP application and review process makes it possible to evaluate and resolve safety and environmental issues related to siting before the applicant makes large commitments of resources. If the ESP is approved, the applicant can "bank" the site for up to 20 years for future reactor siting.

As part of its evaluation of the environmental aspects of the action proposed in an ESP application, NRC prepares an EIS in accordance with 10 CFR 52.18. The EIS must address impacts of operation of reactors and associated facilities. In a review separate from the EIS process, NRC analyzes the safety characteristics of the proposed site and emergency planning information.

Based on the NRC's review of the ESP application, public comments during scoping, comments from the Commonwealth of Virginia, and a letter from Hanover County, it was established that water supply and water temperature issues merited specific scrutiny by the NRC in their review of the application. Pacific Northwest National Laboratory staff developed a model LakeWBT to assist in bounding water supply and water temperature impacts associated with the proposed ESP facility on Lake Anna and North Anna River downstream from the lake. This report describes the LakeWBT and its predictions when applied to bound the water budget and temperature impacts of a proposed facility at the North Anna site.

LakeWBT does not represent a state-of-the-science coupled process model. Field data required to calibrate such a model were not available at this site. Instead of providing highly detailed predictions, LakeWBT bounds the impacts. LakeWBT incorporates several bounding approaches. Several of the approaches were too conservative based on comparison with observations. Results from one of the bounding approaches are considered representative of the impacts.

1.1 Plant Parameter Envelope

As described in Subpart A of 10 CFR Part 52, the applicant for an ESP need not provide a detailed design of a reactor or reactors and the associated facilities but must provide sufficient bounding parameters and characteristics of the reactor or reactors and the associated facilities so that an assessment of site suitability can be made. Consequently, the ESP application may refer to a plant parameter envelope (PPE) as a surrogate for a nuclear power plant and its associated facilities.

A PPE is a set of values of plant design parameters that an ESP applicant expects bounds the design characteristics of the reactor or reactors that might be constructed at a given site. The PPE values are a surrogate for actual reactor design information. Analysis of environmental impacts based on a PPE approach permits an ESP applicant to defer the selection of a reactor design until the construction permit (CP) or combined license (COL) stage. The PPE reflects upper bounds of the values for each parameter that it encompasses rather than the characteristics of any specific reactor design.

1.2 Proposed ESP Facility

The PPE provides bounding constraints on portions of plant water use. Other constraints on plant water use are based on site-specific information. The two proposed ESP units involve considerably different cooling systems with vastly different water needs. The proposed ESP Unit 3 would utilize once-through cooling and the Waste Heat Treatment Facility (WHTF) in the same manner as the existing two NAPS units.

The proposed Unit 4 would utilize dry cooling towers. Whereas wet cooling towers rely primarily on the latent heat of vaporization of water to satisfy cooling demands, dry towers rely solely on the much smaller sensible heat exchange between the air and the water in an enclosed radiator. The consumptive cooling water demands for dry cooling towers are negligible. Unit 4 will not be discussed further in this report.

The primary water demand for the proposed ESP Unit 3 is for condenser cooling. The proposed plant would be limited to withdraw 1,140,000 gpm through the intake structure. The once-through portion of the cooling system would return approximately the same amount of water to the discharge canal and the WHTF. The elevated temperature of the discharge would result in induced evaporative water losses, which are in addition to the natural (ambient) evaporative water losses from the lake. The induced evaporation the cooling system design is not included in the PPE and is a site-specific parameter. Only that volume of the water withdrawn from the lake through induced evaporative loss is considered a consumptive use.

During normal operation at full power, based on the PPE, the primary cooling system for each unit is required to reject 2800 MW (9.7 BTU/hr) to the environment. ESP Unit 3 will reject this heat load via a once through cooling system. This design is the same as for NAPS Units 1 and 2 in that Unit 3 will withdraw water from Lake Anna and discharge the heated effluent to the discharge canal. Based on the PPE the maximum temperature rise between the intake and the discharge will be 18 °F and the maximum discharge temperature is 127 °F. The PPE also states that the flow rate through the condenser will not exceed 1,140,000 gpm.

During low water conditions, the existing two NAPS units are allowed to operate down to 244 ft MSL. While the applicant is attempting to have the minimum pool elevation lowered to 242 ft MSL, the analysis described herein assumes that minimum pool elevation is 244 ft. The applicant is proposing that ESP Unit 3 would also be allowed to operate down to 242 ft MSL.

The normal cooling needs of Unit 3 will be provided by a once-through cooling design in conjunction with the WHTF. The once-through/WHTF cooling system relies primarily on evaporative heat transfer and long-wave heat transfer to the atmosphere to dissipate the rejected thermal load. This design results in less consumptive use of water than a conventional cooling tower for the same load. The PPE estimates a maximum evaporative loss of a once-through design to be 11,700 gpm (or 26 cfs) as compared to 19,500 gpm (or 43 cfs).

2.0 LakeWBT Model Development

Lake Anna is a hydrodynamically complex reservoir, whose circulation is impacted by numerous factors including: operation of the existing NAPS units, downstream water needs, lakeside housing with an associated desire for a constant WSE, variable upstream inflows, dynamic meteorological values, and operation of the Dike 3 weir. These features combine to produce zones within the lake containing large vertical and horizontal gradients of both water temperature and velocity.

Numerical simulation to examine impacts of ESP Unit 3 requires understanding of the major flow features contained within the lake, especially variations of water velocity at key locations. Unfortunately, this information is unavailable at present. Without adequate water velocity data, only an un-calibrated approximation of travel time from plant outfall to intake can be performed. Travel time information is critical, because the decay of water temperature from an elevated level to equilibrium temperature is not linear, but exponential. Therefore, the longer the water is exposed to the atmosphere the larger the loss of excess heat. In addition, small errors in travel time can compound to produce large errors in the estimation of heat flux at the water's surface.

Assuming adequate field data was available, a 3-D non-hydrostatic computational fluid dynamics (CFD) model should be applied to simulate the Dike 3 jet and near-field entrainment area. This zone is critical to understanding mixing in the main body of the lake, and will required detailed water velocity information as well as information regarding how Dike 3 will be operated once ESP Unit 3 is constructed. Outside of this zone, a 3-D hydrostatic CFD model should be applied to simulate the lateral and vertical temperature distribution within Lake Anna, including the WHTF. Because an adequate amount of field data was not available to perform a 3-D CFD modeling study, a simplified transient model was developed to estimate water surface elevations in the lake. This bounding model, LakeWBT, is described in the following sections.

2.1 LakeWBT Bathymetric Schematization

Digital 1:24,000 scale digital raster graphic (DRG) quadrangles of Lake Anna were downloaded from the Department of Geography at Radford University (http://www.runet.edu/~geoserve/Virginia.html). These images served as the source dataset for bathymetry to support LakeWBT. A mosaic of the raw images was used to generate a geo-referenced base map that was then digitized using the ESRI™ software package ArcMap™ 9.0. The resulting 10 ft interval contours from elevation 180 to 250 ft MSL are shown in Figure 1.

A continuous surface was created from these contours, the surface of which was clipped at the source dataset elevation extremes. This surface was broken into three zones based upon observed water temperatures in the lake (see Figure 2): the WHTF, the main lake from North Anna dam upstream to the Highway 208 Bridge, and the lake arms upstream of the Highway 208 Bridge. Impounded surface areas and volumes were then calculated for each section as a function of water surface elevation, the results of which are presented in Table 1.

Lake Anna			WHTF		
elevation (ft)	area (ac)	volume (ac-ft)	elevation (ft)	area (ac)	volume (ac-ft)
250	13,068	312,171	250	3,194	64,082
240	9,219	200,737	240	2,120	37,515
230	6,553	121,877	230	1,374	20,045
220	4,418	67,021	220	830	9,026
210	2,715	31,354	210	418	2,787
200	1,281	11,377	200	139	
190	523	3,257			
180	129				

Main Lake			Lake Arms		
elevation (ft)	area (ac)	volume (ac-ft)	elevation (ft)	area (ac)	volume (ac-ft)
250	5,540	174,374	250	4,334	73,715
240	4,528	124,032	240	2,571	39,190
230	3,614	83,323	230	1,565	18,509
220	2,803	51,240	220	786	6,755
210	2,034	27,055	210	263	1,512
200	1,101	11,377	200	40	
190	523	3,257			
180	129				

Table 1 Computed areas and volumes as a function of water surface elevation for the various zones of Lake Anna

Lake Anna, a man-made reservoir formed when the North Anna Dam began to impound water, is comprised of numerous fingers and arms. The lake is approximately 17 miles long, and several dikes have been constructed to increase travel time from the discharge canal exit to the intake. Trapezoidal connecting canals have been constructed to convey flow from the three ponds formed by these dikes, and are labeled as ponds 1 through 3 in the figure. The collection of ponds and connecting canals are collectively labeled as the WHTF.

Water leaving the discharge canal may only exit the WHTF through Dike 3. This dike contains a submerged discharge structure with adjustable stop logs to baffle exiting discharge. This structure creates a positively buoyant high velocity (typically >6 ft/s) jet, that was designed to quickly entrain cooler main lake water.

The Massachusetts Institute of Technology (MIT) developed, calibrated, and validated a numerical model of Lake Anna. This model accurately produces results of the lake with the two existing reactors operating after undergoing a detailed calibrated following construction of the existing reactors (MIT, 1984). Since the model hydrodynamics are highly tuned to existing travel time conditions, especially through the WHTF, and since the decay of water temperature is exponential towards equilibrium, the model would need to be recalibrated once again to accurately predict water temperatures for conditions when the ESP reactor(s) are operating. This is not possible without the collection of field data obtained after the ESP reactor(s) have been constructed, and as was done previously after both units went online in 1980.

MIT model simulation results for existing reactor conditions show that year-to-year variations in daily averaged water temperature are relatively small for both wet and dry watershed conditions. Water temperatures shown in Figure 2 span a six-year period that includes years of relatively constant WSE and drought years when the WSE dropped approximately 5 ft below normal pool elevation. Of note in this figure are the relatively small variations in water temperature throughout the main lake, and that these temperatures are several degrees above equilibrium temperature. Data collected in the arms upstream of the Highway 208 Bridge indicate that these zones are at approximately equilibrium temperature, suggesting that little excess heat generated by the existing units are dissipated in these upstream regions.

Because the yearly cycle of water temperature is fairly consistent for the existing two reactor configuration, an approximation later used by LakeWBT is the yearly cycle of date-average water temperatures shown in Figure 3. This figure shows the gradual dissipation of heat through the system as water travels from the discharge canal, through the WHTF, and back towards the intake. Of note from these results are that Pond 2 discharge water temperatures are only slightly higher than Dike 3 (i.e. Pond 3 discharge) water temperatures. Also of note from these results are that the WHTF arm water temperatures are approximately equal to the temperature at Dike 3. These results suggest that a large quantity of heat energy is being lost to the atmosphere between the discharge canal and Pond 2, and that even at discharge from the WHTF to the main lake, water temperatures are significantly above equilibrium temperature.

2.2 LakeWBT Model Boundary Conditions

The model needs a time series of boundary conditions as input to the model both for calibration and simulation. Inflows upstream to the lake are required for both model calibration and model simulation. Discharges from the dam are required for model calibration. In simulation mode the discharges are predicted for each of the scenarios. Meteorological data is need for both model calibration and model simulation. Additionally, water temperature conditions were derived based on output from another model.

2.2.1 Inflows

The principal tributaries of Lake Anna include the North Anna River, Pamunkey Creek, and Contrary Creek. Unfortunately, none of these tributaries contained stream flow gages during the 1996 through 2001 period when Lake Anna experienced a critical drought period. Because this critical drought period is the most severe on record, it was desirable to use this period and to develop synthetic inflows from an adjacent basin.

Daily average streamflows for Little River near Doswell, VA were obtained from US Geological Survey (http://waterdata.usgs.gov/nwis) gage 01671100. The size of the Little River watershed at this gaging station is 107 mi^2, which is approximately 3.2 times smaller than the North Anna watershed where it enters Lake Anna. Inflows to Lake Anna were therefore computed during the simulation period by multiplying the watershed scale ratio to the daily average Little River discharges.

2.2.2 North Anna Dam Releases

North Anna Dam releases employed a rating curve based on observed streamflow downstream of dam when the water surface elevation (WSE) exceeded 250 ft. Otherwise, the release is 40 cfs down to a WSE of 248 ft. Below WSE of 248 ft, based on the NPDES permit conditions, the discharges is decreased to 20 cfs.

2.2.3 Meteorology

Meteorological information about the atmosphere above the lake is necessary to compute evaporation in LakeWBT. Air temperature, dew point temperature, and wind speed were obtained from the Richmond Airport (EarthInfo, 2003), which was the nearest location that colleted data during the critical drought period. Hourly observed data were used as model inputs for the simulated drought period.

Precipitation falling onto Lake Anna was considered an inflow boundary condition for the water budget model. Total accumulated precipitation on each day was obtained from

National Climate Data Center (NCDC), and was originally collected at the Richmond Airport (NCDC, 2004).

2.3 LakeWBT Water and Heat Budget Process Representation

Analogous to a water budget, a generalized heat budget begins by considering the quantity of heat contained in a water body with a specified initial volume and temperature. Over time, heat will either enter or depart from the system through one of the volume's boundaries. Surface water inflows and outflows add or subtract heat to the system, as does groundwater although this flux is typically difficult to quantify.

Heat flux at the surface of the water body can be decomposed into the five parameters shown in Figure 4. A body of water is defined to be at equilibrium temperature when the flux of incoming and outgoing heat is equal; in other words, when the net heat flux is zero. Because the values of solar radiation, evaporation, etc. vary dramatically throughout the diurnal cycle, equilibrium temperature is generally calculated on a daily time step. Typical daily-average values of heat flux at mid-latitudes are shown in Figure 4 (Edinger, 1974). All the components except solar are nonlinear with respect to lake surface temperature. This nonlinear behavior makes the overall heat budget nonlinear.

2.3.1 Evaporation Rate Formulations

Evaporation rate the water surface represents the volume per surface area per unit time of liquid water that is vaporized into the atmosphere. Numerous formulations to compute evaporation rate exist in the technical literature (see McCutcheon (1989), Edinger(1974), TVA(1972), Brutsaert(1991), Bras(1990)). Generally however, most formulations can be written in the following form:

$$E = f(W)(e_{ws} - e_a) \tag{1}$$

where E is the evaporation rate (m3/s/m2 or m/s), ea is the air-vapor pressure (mbar), e_{ws} is the saturation vapor pressure of the air adjacent to the water surface (mbar), and $f(W)$ is a wind speed polynomial in the general form of:

$$f(W) = a_0 + a_1 W + a_2 W^2 ... \tag{2}$$

where a_0, a_1, and a_2 are constants ($mbar^{-1}$)and W is the speed of the wind at 2 m above the water surface(m/s).

Two separately recommended formulations from TVA (1972) and Edinger et al. (1974) were tested for sensitivity in the application of LakeWBT to Lake Anna. Simulation results produced almost identical monthly average evaporation rates with both formulations. The final formulation used to compute management scenarios for Lake Anna is the formulation recommended by TVA (1972), which is also reported in Bras(1990), and is credited to Marciano-Harbeck (1954). Formulations for both evaporation rate and vapor pressure calculations (Clausius-Clapeyron Equation) are as follows:

$$E = 1.523x10^{-9}\ W\ (e_{ws} - e_a)$$
$$e_{ws} = 6.11\exp\left[\frac{L_{water}}{R_v}\left(\frac{1}{273.15} - \frac{1}{(T_{water} + 273.15)}\right)\right] \quad (3)$$
$$e_a = 6.11\exp\left[\frac{L_{dew\ pt}}{R_v}\left(\frac{1}{273.15} - \frac{1}{(T_{dew\ pt} + 273.15)}\right)\right]$$

where T represents water surface and dew point temperature in deg-C, R_v is the gas constant for water vapor (461 J/(°K kg)), and L is the latent heat of vaporization (J/kg) from Bras (1990), computed with either the water surface or dew point temperature, as appropriate:

$$L = 4186.8\,(597.3 - 0.57 * T) \quad (4)$$

The evaporation rate equations are non-linear with respect to temperature, and relatively small variations in surface and/or dew point temperatures can produce relatively large changes to the instantaneous evaporation rate. Additionally, any bias in the estimation of surface water temperature can accumulate over time to produce large errors between calculated and actual evaporation rates.

Negative evaporation rates, also known as condensation, will occur whenever the water surface temperature falls below the atmospheric dew point temperature. Surplus water in the atmosphere reenters the liquid phase, thereby releasing to the water surface the heat of condensation which is equal to the heat of vaporization. This heat input by condensation requires that condensation take place at the water surface. In many cases, the presence of condensation nuclei in the air may cause condensation to occur in the air above the water surface. When this occurs, the heat of condensation is released to the air under fog formation, not to the water surface. Therefore, heat input into the water surface by condensation cannot always be easily assessed. In LakeWBT, any negative evaporation rates were reset back zero and the heat gain by the water surface due to condensation was neglected.

2.3.2 Direct Scaled Water Temperature Approach

The first bounding approach attempted applied the most conservative approach. The PPE values for maximum heat load rejected and discharge were used to calculate the temperature rise in the lake. This method is conservative because it assumes that none of ESP Unit 3's waste heat exchanges heat with the atmosphere. Drawdown calculations compute evaporation (volume lost) based on these elevated temperatures, but evaporative cooling (Joules) does not get fed back into heat budget. Given the high recirculation rate between the intake and discharge (particularly during the critical period), the predicted impacts were very severe. Figure 5 shows the temperatures which provided the basis of the direct scaled temperature approach. The temperatures show a 14 F rise over the observed from the assumptions mentioned above. The results are overly conservative and result in the severe results shown in Figure 6.

2.3.3 Constant Temperature Hot Thermal Pool Approach

The second approach attempted to be less conservative and more realistic that the direct scaled temperature approach and too be useful in both the lake temperature and water budget assessments. Clearly there is a tradeoff between conservatism in lake temperature and water budget calculations. Increasing evaporation reduces the heat in the lake but also increases the water in the lake. Decreasing evaporation increases the heat in the lake but also reduces the water loss from the lake.

This approach incorporated another component of heat loss (long-wave back radiation) that is a significant source of heat loss in lakes (see Figure 4). The approach involved dividing the lake into two volumes. One volume was set at a user specified threshold temperature. This threshold temperature had to be higher than the highest equilibrium temperature (natural lake temperature). This volume remained at the constant threshold temperature through the simulation, however, its volume as a fraction of the total lake volume would vary over time. The temperature of the second volume was the equilibrium temperature, which varied over time. Both of the volumes evaporated water according to their respective temperatures. Both volumes also lost heat according to Boltzman's Equation for black body radiation. The relative volumes of each was assumed to equal the relative surface areas. Generally, due to buoyancy of the warmer water, the surface area of the warmer would be larger making this a conservative assumption relative to heat loss. Heat fluxes (evaporative cooling, black body radiation, reject heat) resulted in exchanges in water between the two volumes to maintain the appropriate temperatures in the volumes while preserving the total energy content.

Example results for the constant temperature hot thermal pool approach are shown in Figures 7 and 8. Figure 7 shows the results of water surface elevation for all the scenarios with a threshold temperature of 95 F. Consistent with expectations, the cooling tower results in a greater drawdown than the once-through cooling design for the ESP Unit 3. Figure 8 shows the thermal impact of the once-through cooling design greater than the other alternatives. Again, this outcome is consistent with expectations. However, the fraction of the lake experiencing the threshold temperature is higher than observations would suggest.

2.3.4 Newton's Law of Cooling Approach

The third and final bounding approach was based on Newton's Law of Cooling which defines an exponential decay in temperature between a body of a limited thermal mass in contact with another body of infinite thermal mass and constant temperature. This approach involved several steps. First the natural background evaporation was computed. Next the forced evaporation from the existing NAPS units was computed using the exponential decay adjusted for volume. The inflow adjustment was estimated to match the predicted and observed WSE. This residual error requiring inflow adjustment was shown to be very small.

The MIT model temperature model results were shown to be well calibrated and thereby provided a reliable baseline for lake temperatures. By using upstream temperature estimates some conservatism was provided. The temperature of the WHTF was assumed to be represented with the discharge canal temperature. In a similar manner, the temperature of the WHTF arms, main lake, and lake arms where set to the MIT values for Dike 3, Burrus Point, and the equilibrium temperature, respectively.

Once these initial values have been established the model imposes evaporation rates for Unit 3 based on the PPE values. The PPE estimate for once through would be difficult to validate and monitor. However, the evaporative loss for a wet cooling tower is clearly bounding. WSE values were calculated for both PPE values. In these calculations the changes in surface area and volume as a result of drawdown were explicitly considered.

The monthly natural and forced evaporation fluxes for the critical period is are shown in Figure 9. The evaporation for each of the lake components is shown in Figure 10.

3.0 LakeWBT Simulation Results

While the entire period of 1978 through 2003 was used for calibration, the critical period was the 2001 through 2003 period. During this period the region experienced a severe drought and concern over water use conflicts were elevated as the WSE in Lake Anna dropped to record lows. The inflow, outflows, and inflow adjustment was small and on the order of 0.02 cfs (see Figure 11). The natural evaporation (39 in/yr) estimated closely matches van der Leeden, et. al. (1990).

Figure 12 shows the combined results for all four scenarios. This results are also summarized in Table 2. Figures 13 through 19 show the water fluxes and water surface elevations for each of the four scenarios.

Table 2 Lake Anna drawdown calculation results. Average forced and natural evaporation rates, averaged over then critical drought period, are also presented.

Scenario	Sim Avg Nat Evap. (cfs)	Sim Avg Forced Evaporation (cfs)	Minimum WSE (ft)
No Units	57.3	0	247.5
Units 1 & 2	55.6	47.2	245.1
U 1 & 2 + U 3 Once Thru	54.2	69.2	243.4
U 1 & 2 + U 3 Tower	53.3	83.1	242.4

4.0 Conclusions

The only plant operational activity identified by staff that would result in a detectable hydrological alteration of the environment is the discharge of waste heat from Unit 3. The additional discharge entering the discharge canal from the Unit 3 will result in shorter times for the water to travel from the discharge back to the intake. Similarly, a decrease of lake volume due to additional induced evaporation from Unit 3 would also reduce the travel time between the discharge and the intake.

During normal operation at full power, based on the PPE, the primary cooling system for each unit is required to reject 2800 MW (9.7 BTU/hr) to the environment. Unit 3 will reject this heat load via a once through cooling system. This design is the same as for NAPS Units 1 and 2 in that Unit 3 will withdraw water from Lake Anna adjacent to the location of the existing intakes and discharge the heated effluent to the discharge canal. The PPE also states that the flow rate through the condenser will not exceed 71,900 L/s (1,140,000 gpm). The once-through portion of the cooling system would return approximately the same amount of water to the discharge canal and the WHTF. The elevated temperature of the discharge would result in induced evaporative water losses, which are in addition to the natural (ambient) evaporative water losses from the lake. The induced evaporation the cooling system design is not included in the PPE and is a site-specific parameter. Only that volume of the water withdrawn from the lake through induced evaporative loss is considered a consumptive use. The LakeWBT bounding analysis used the applicant's PPE estimates of induced evaporation for a once-through system 11,700 gpm, and evaporation for a wet cooling tower 19,500 gpm.

The existing NAPS units are the largest users of water in the region, and the addition of a third unit would add to this use. Most of the NAPS water usage of water drawn from Lake Anna for condenser cooling is non-consumptive as it is entirely returned to the lake. However, although there is no consumptive use of water between the intake and discharge, the elevated temperature of the discharged water results in additional induced evaporative losses from the remainder of Lake Anna, and a third unit's once-through cooling system would add to this loss. While the increased circulation of water within Lake Anna resulting from the increased discharge from the Unit 3 will be detectable, it is only an impact inasmuch as it results in a change in the quantity and distribution of heat in the lake.

The impacts on water use are related to the water budget. Discharge of the additional condenser cooling heat from Unit 3 to the lake would increase the heat in the lake and increase evaporation. This additional volume of discharged cooling water would also change the hydrodynamic circulation of Lake Anna. The increased evaporation from Lake Anna from a third unit's once-through cooling system would increase the duration that the flow rate from the Lake Anna Dam would be 20 cfs from 5.8 percent to 11.8

percent of the time and the percent of the time the lake level would be less than or equal to 248 ft MSL from 5.2 to 11.6 percent of the time. This will increase the time that the lake level or flow rate will be low.

Long-wave and conductive heat loss are both neglected using the wet cooling tower estimate and therefore make the estimate conservative.

Lake temperature estimates used in the LakeWBT estimation of the forced evaporation of the existing units evaporative losses were obtained from the applicant's calibrated and validated MIT model results. The staff used conservative temperature values from the MIT model as input into the staff's estimation of the evaporative loss. By selecting upstream temperatures, conservatism was enforced. The temperature at the end of the discharge canal was used to represent the main portion of the WHTF. The temperature at Burrus Point was used to represent the main body of the lake. The arms of the main body were assumed to be at the equilibrium temperature.

The staff estimated outflows from the lake based on the current operating rules for Lake Anna Dam. Releases are generally performed to maintain a water surface elevation of 250 ft MSL. When the water surface elevation drops below 250 ft above MSL because of inadequate inflow to offset the natural and induced evaporative losses, the release is maintained at the normal minimum flow of 40 cfs. If the water surface elevation declines below 248 ft MSL, releases were assumed to decrease to 20 cfs immediately. In cases of severe declines in the lake water surface elevation, this assessment took into account the current lake level limit for Units 1 and 2 operation, 244 ft MSL, and for proposed Unit 3 is 242 ft MSL. Once the water surface elevation rose above the intake threshold, the unit(s) were restarted.

The water budget modeling analysis assumed both the existing NAPS units and the once-through Unit 3 operated continuously at a 100% load factor except when the lake dropped below the current threshold, at which point the impacted units cease to operate. Four scenarios, including Unit 3 using an alternate cooling system (wet cooling towers), were selected to estimate the minimum water surface elevations: no units operating; Units 1 and 2 operating; Units 1 and 2 and the proposed Unit 3 (once-through system); and Units 1 and 2 and the proposed Unit 3 (wet tower cooling). The last scenario represents a water use upper bound. When modeling water surface elevations during the critical period of record, specifically targeting the minimum elevation occurring during early October (in the 2nd week) of 2002, the model predicts the following minimum water surface elevations for the various scenarios:

No units operating:	247.8 ft
Units 1 and 2 (existing/observed conditions):	245.1 ft
Units 1 and 2 plus Unit 3 using once through cooling:	243.4 ft

Units 1 and 2 plus Unit 3 using wet cooling tower cooling: 242.4 ft.

These numbers are similar to results provided in the application, in which Dominion estimated that during the critical period, the water surface elevation would drop an additional 2 ft, from below 246 ft to below 244 ft, with the addition of Unit 3 (using wet cooling tower cooling).

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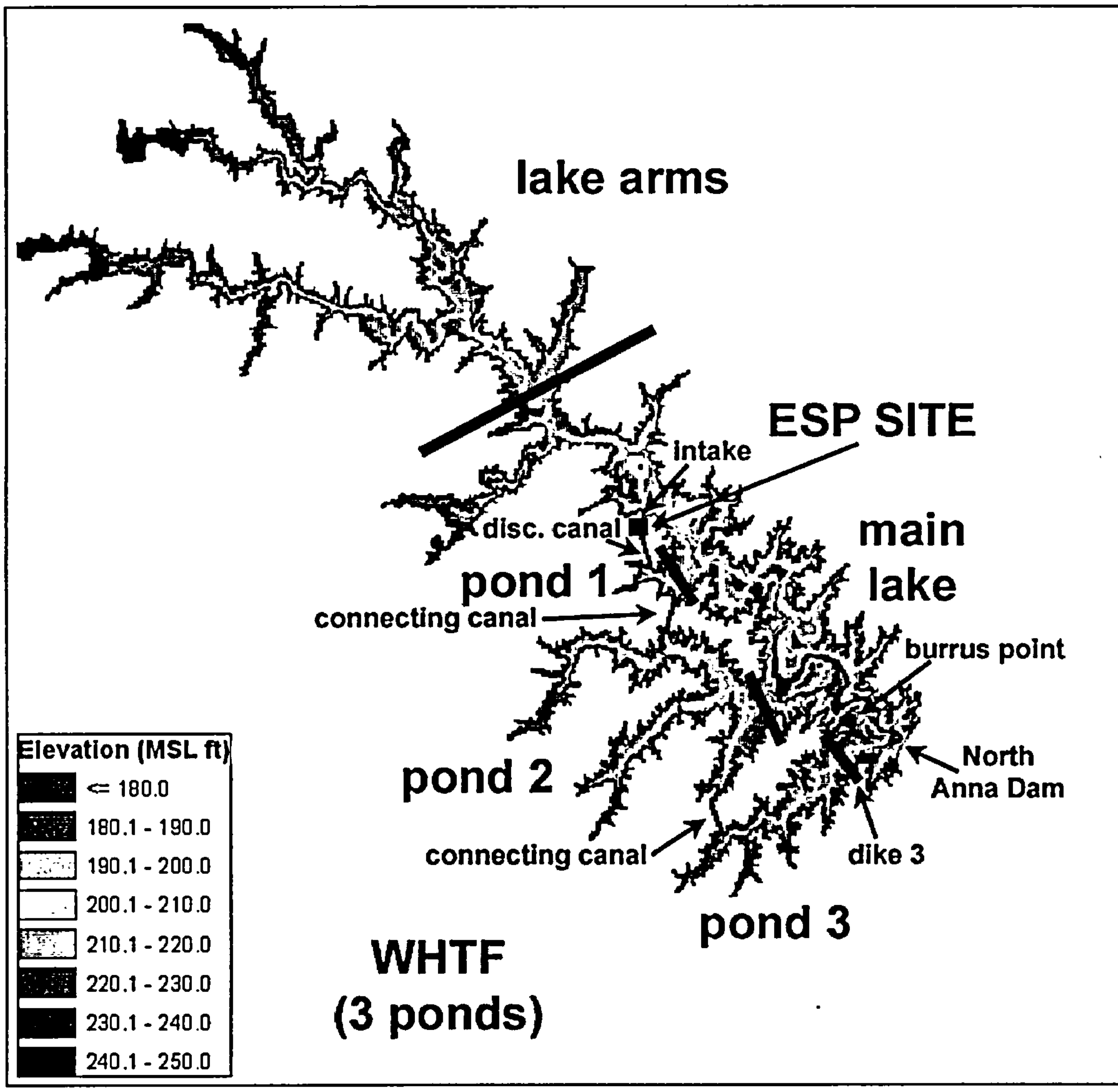

Figure 1 Lake Anna major features

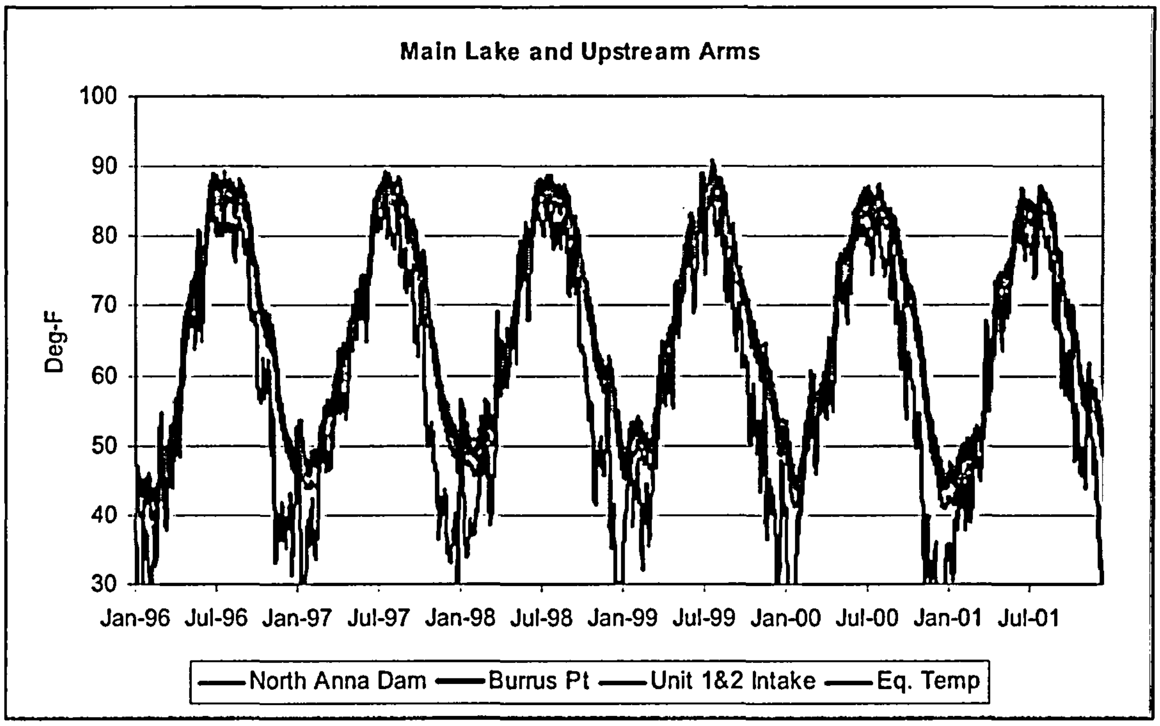

Figure 2 Historical main lake and upstream arm temperatures observed and computed by MIT model

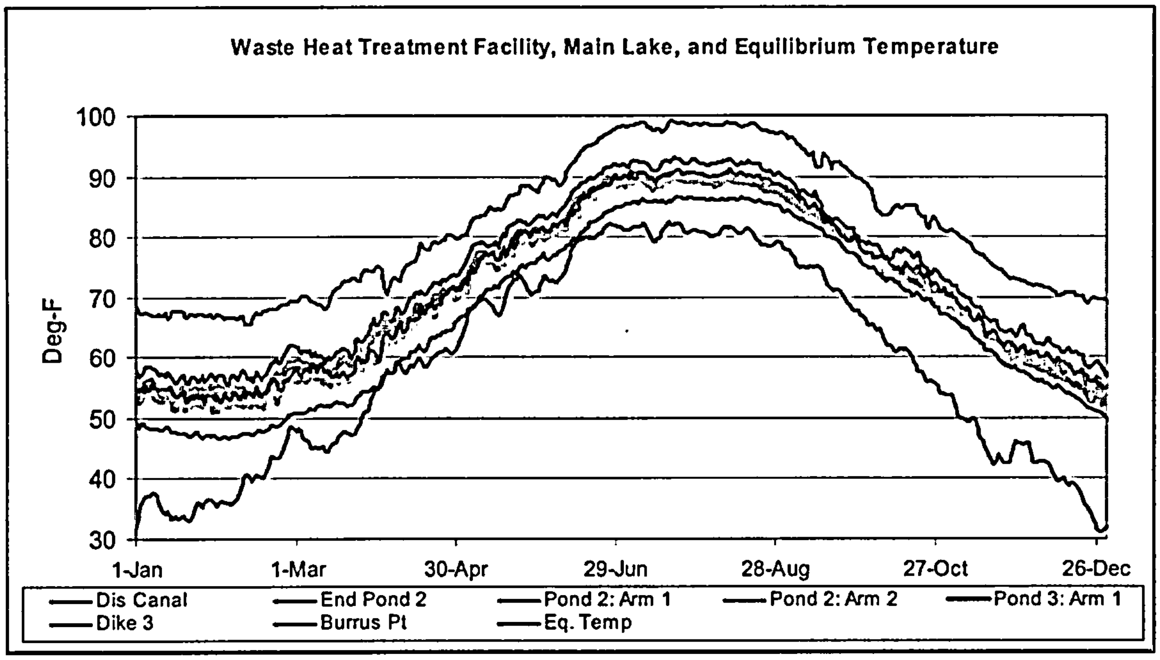

Figure 3 Date-averages water temperatures for the WHTF, main lake, and equilibrium for the period 1996-2001

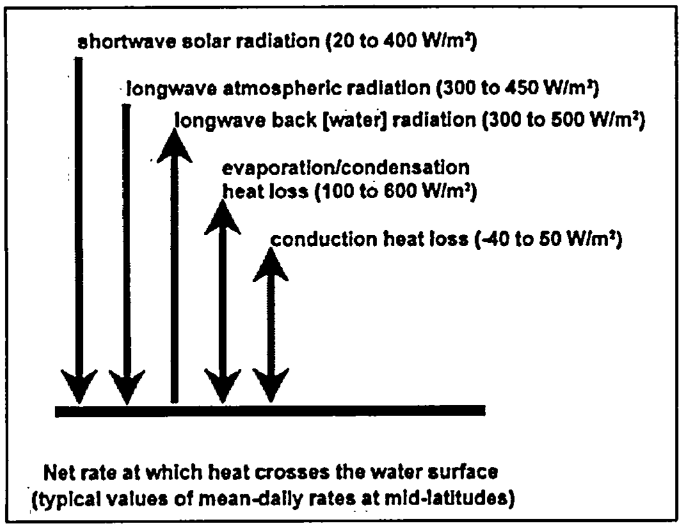

Figure 4 Five principle components used to compute heat flux at the water surface. Values shown are mean-daily values (Edinger, 1974)

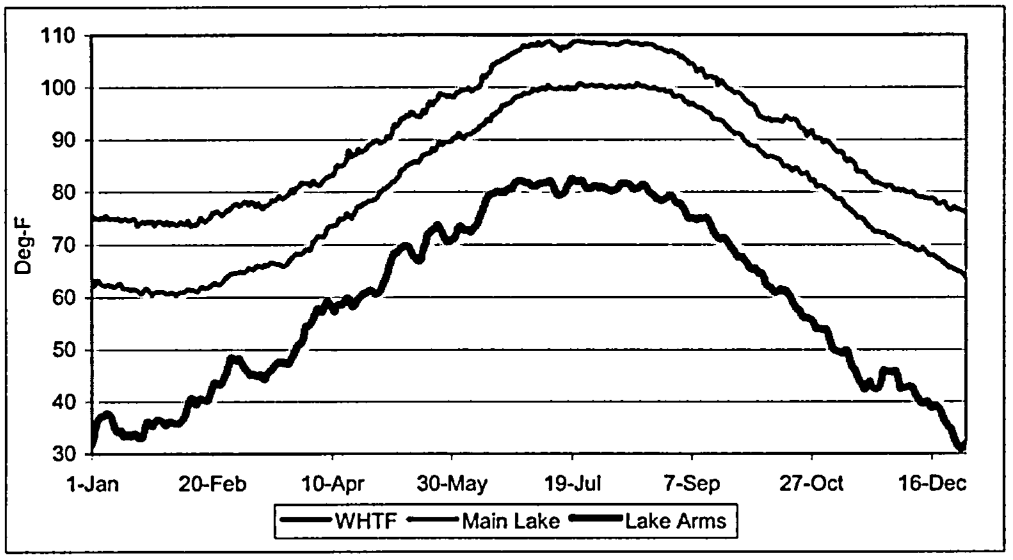

Figure 5 Temperatures which provided the basis of the direct scaled temperature assessment

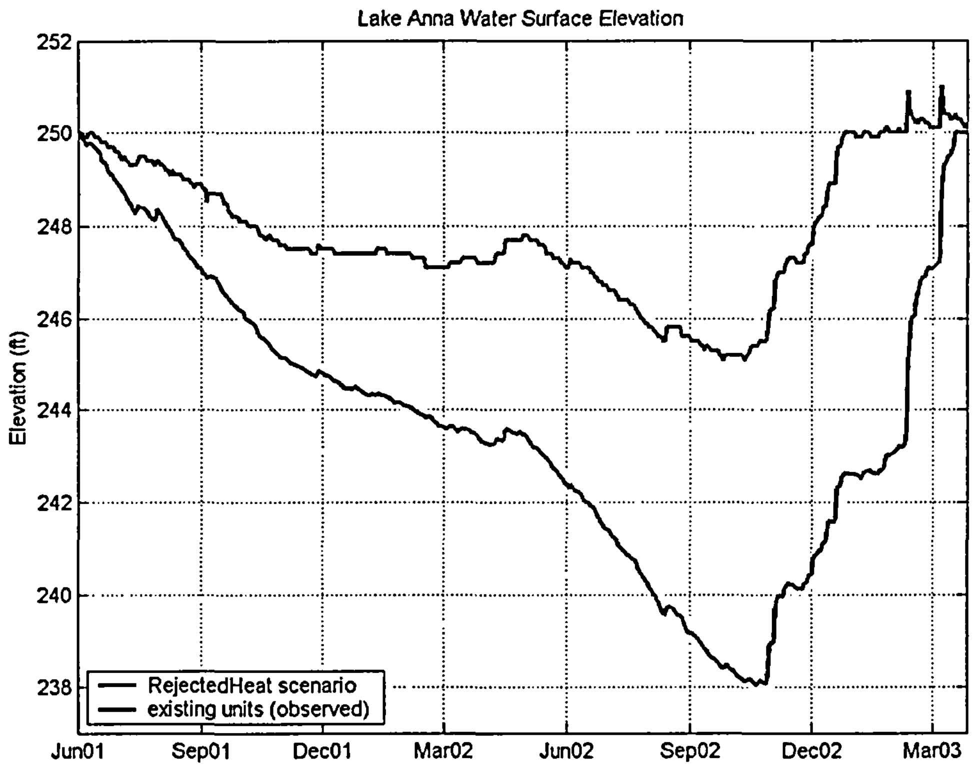

Figure 6 Water surface elevations predicted based on direct scaled temperature approach

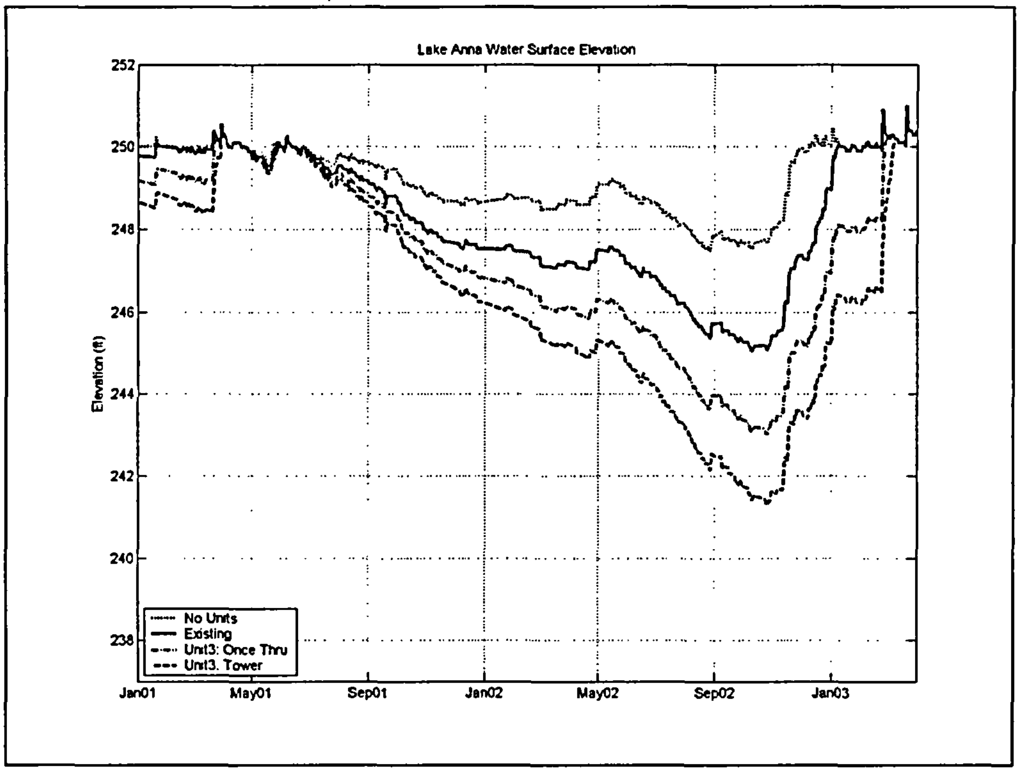

Figure 7 Water surface elevations predicted during the critical period using the constant temperature hot thermal pool approach

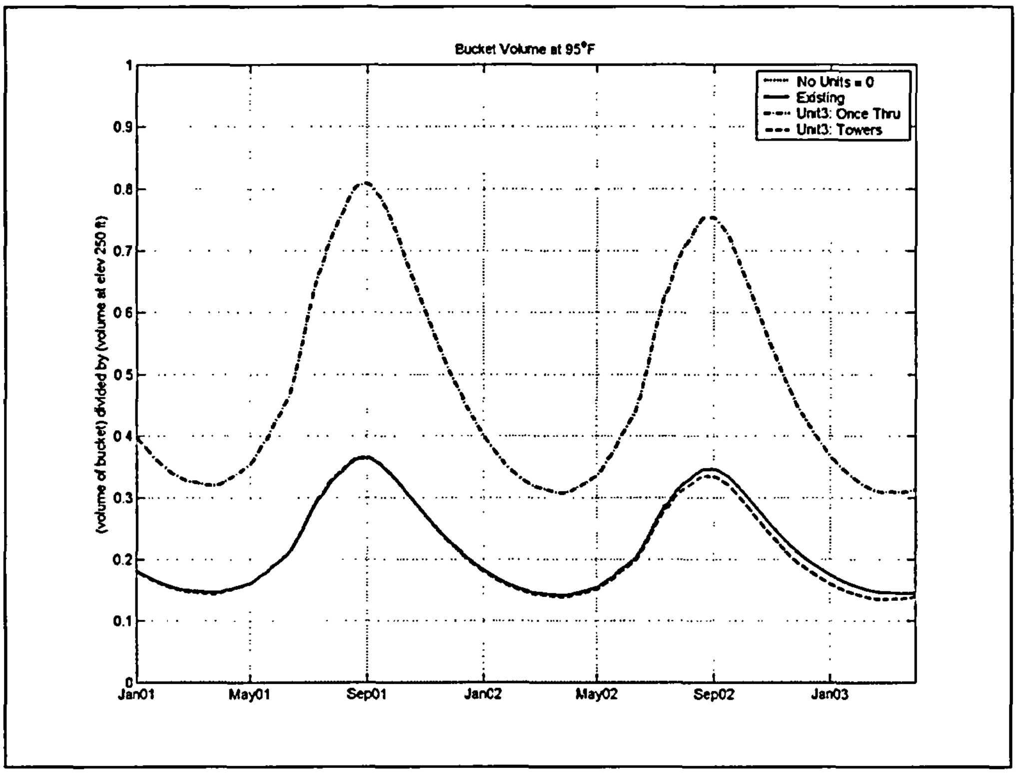

Figure 8 Relative fraction of lake volume as 95 F pool using constant temperature hot thermal pool approach

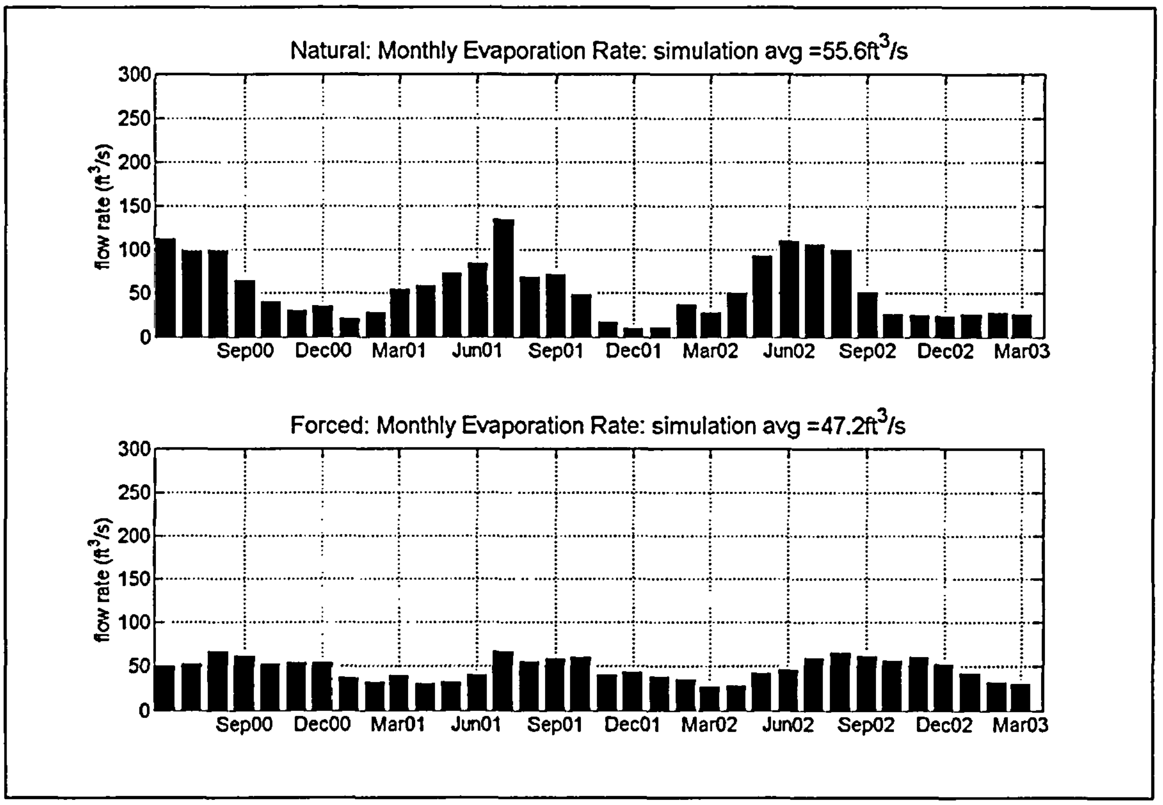

Figure 9 Natural and forced evaporation during the critical period used in Newton method estimation

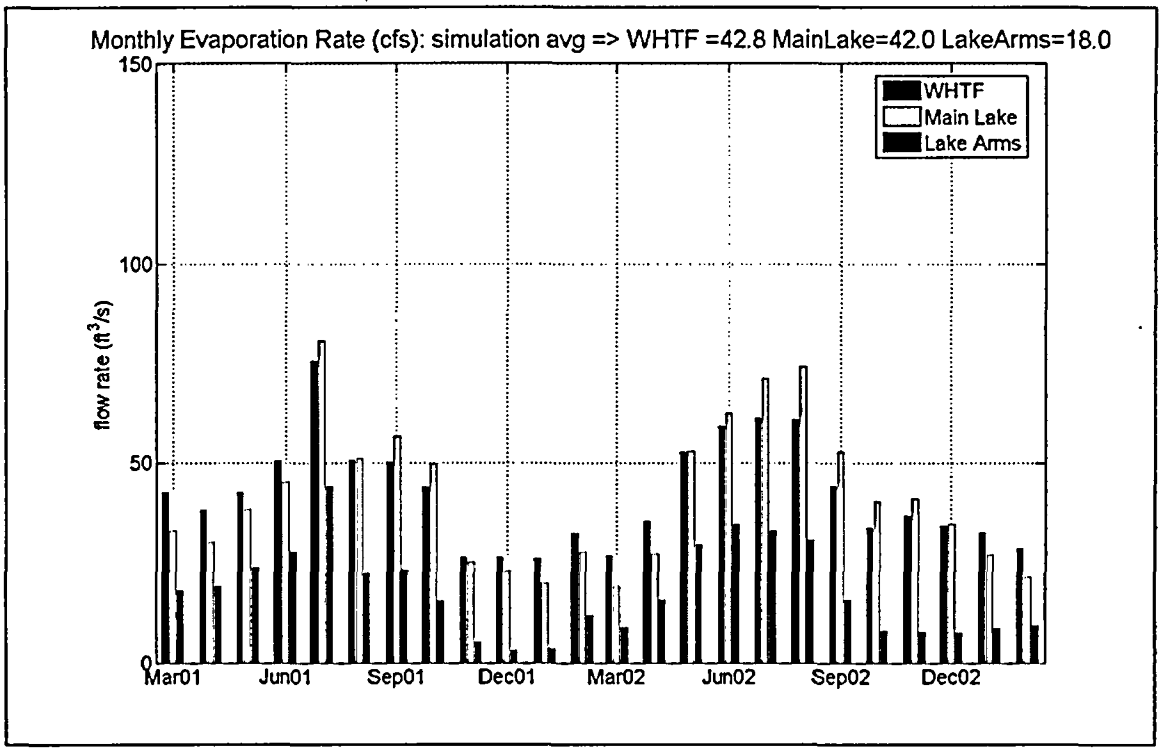

Figure 10 Evaporation from various lake compartments used in the Newton approach (relative surface areas: WHTF = 24%, main lake = 42%, lake arms =33%)

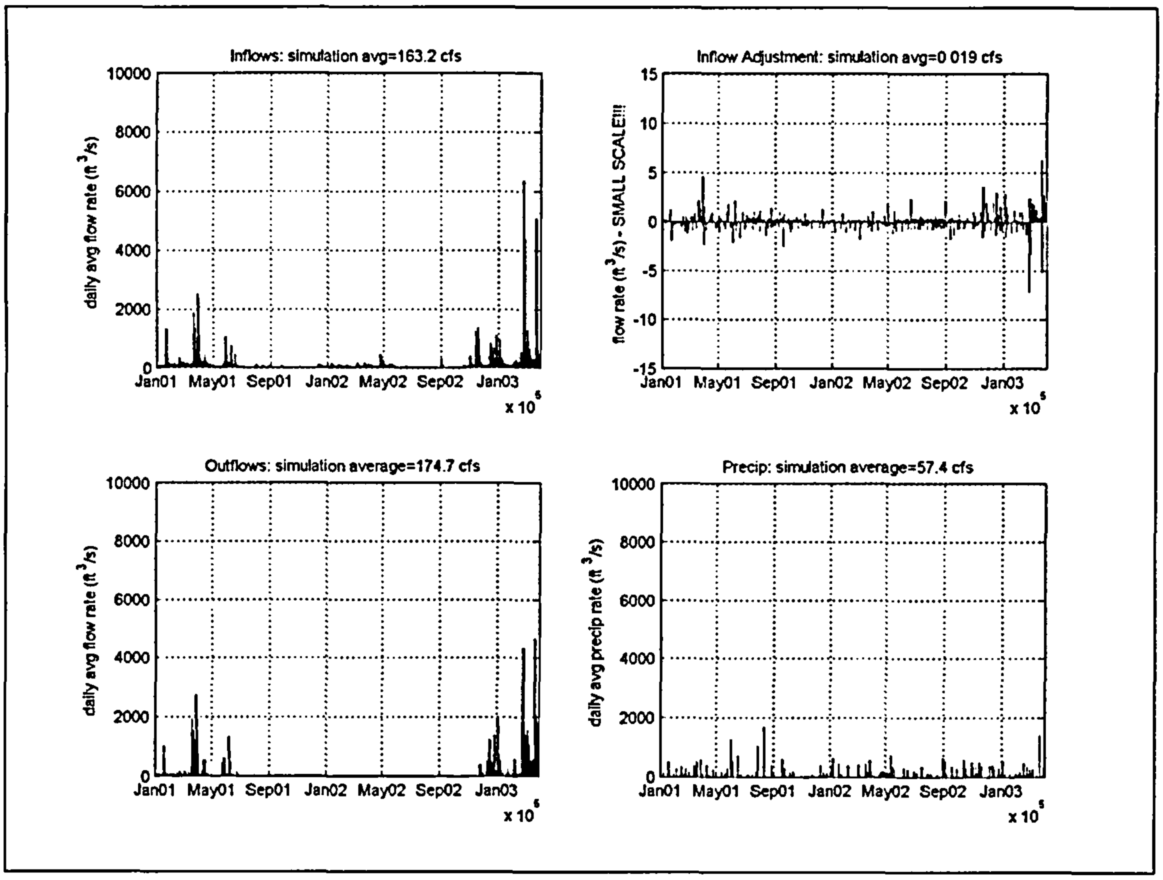

Figure 11 Inflows, outflows and flow adjustments

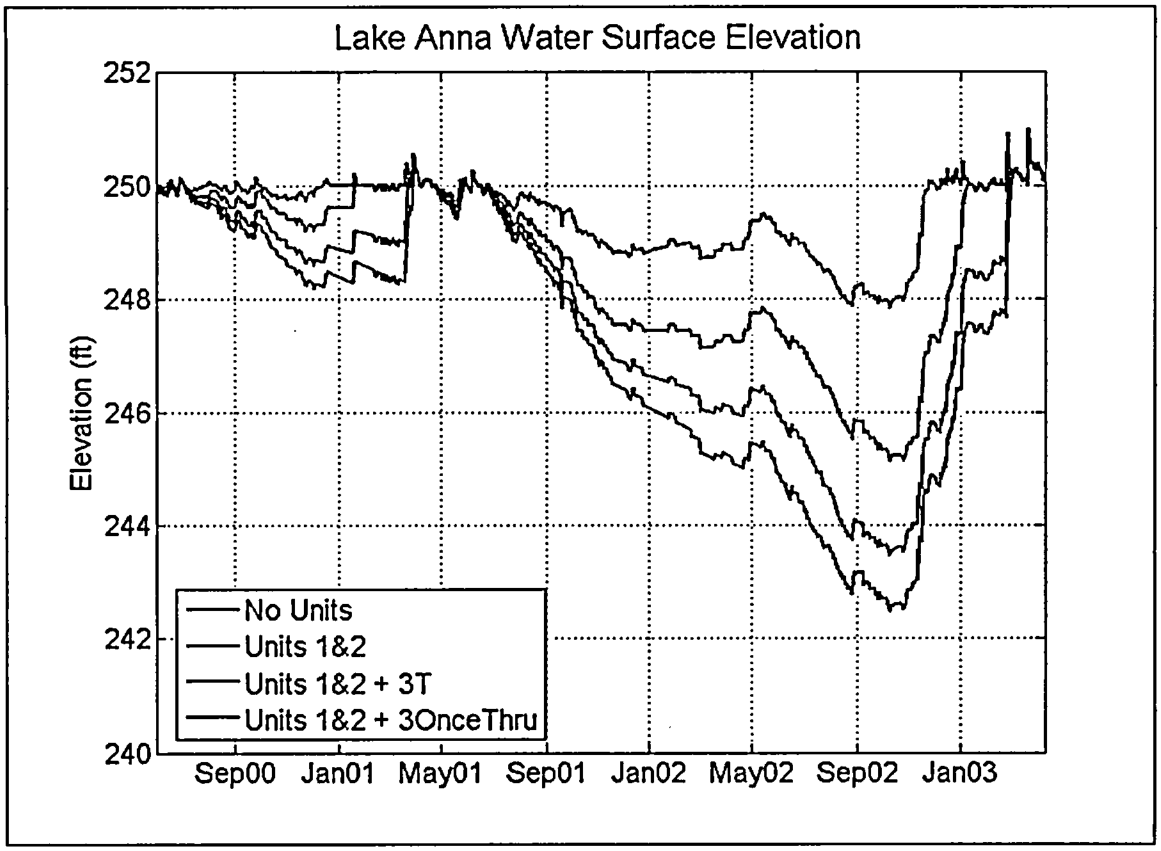

Figure 12 Composite WSE predictions

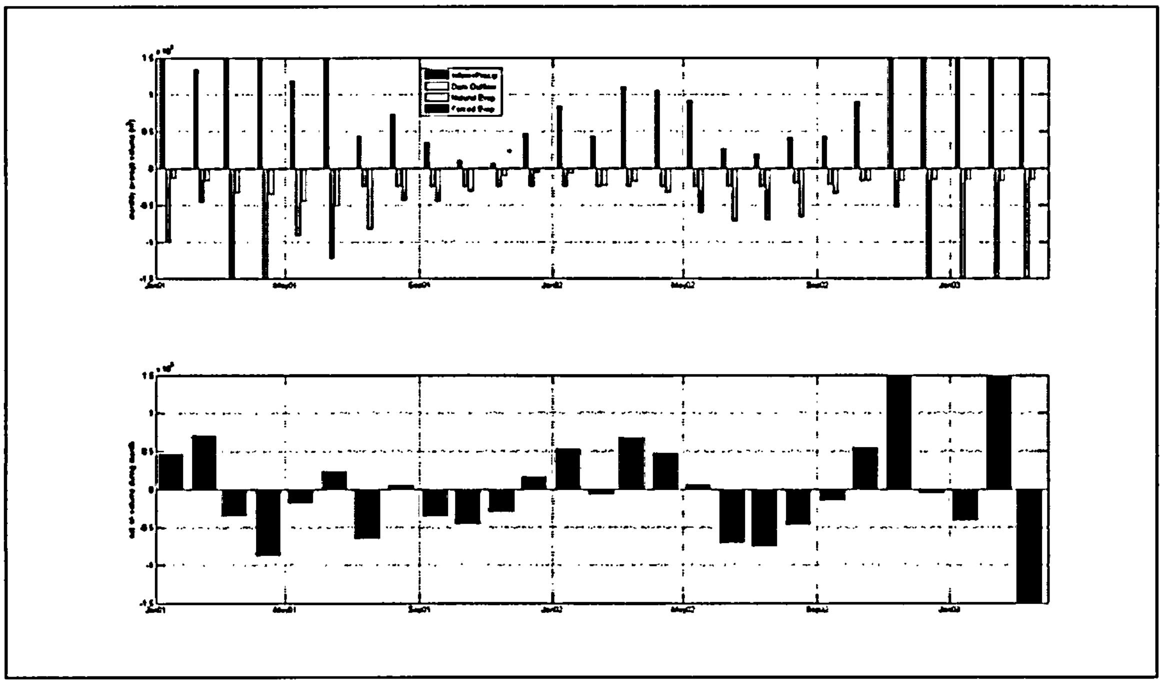

Figure 13 Water Fluxes Baseline (no units operating)

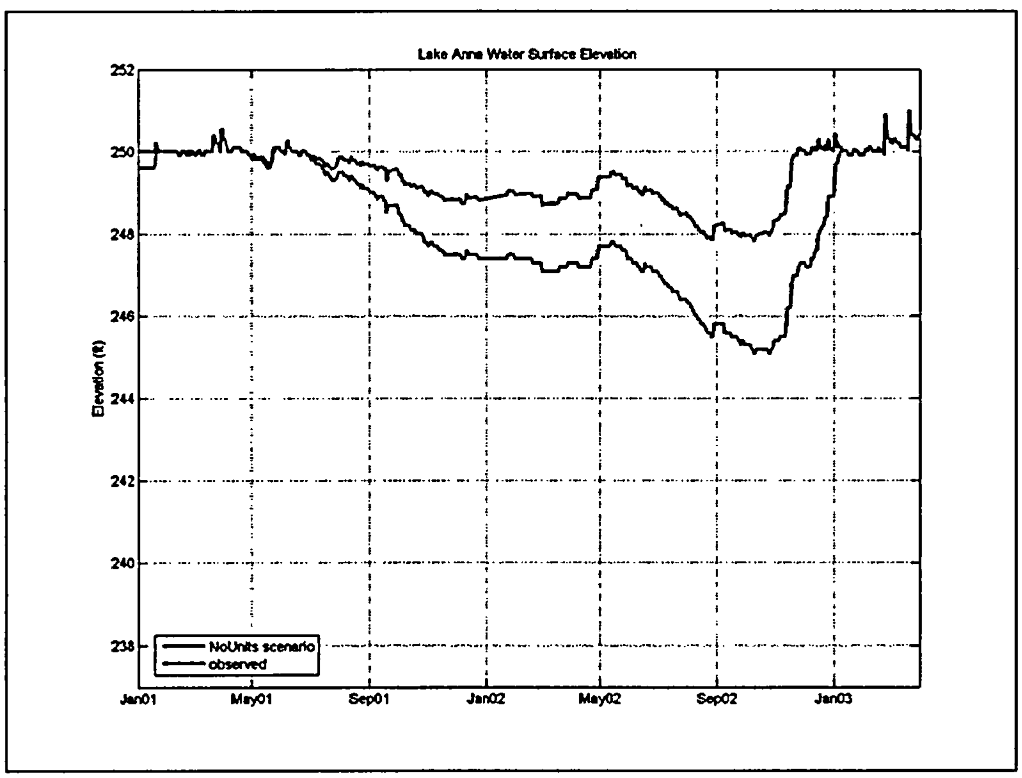

Figure 14 Water Surface Elevation Baseline (no units operating)

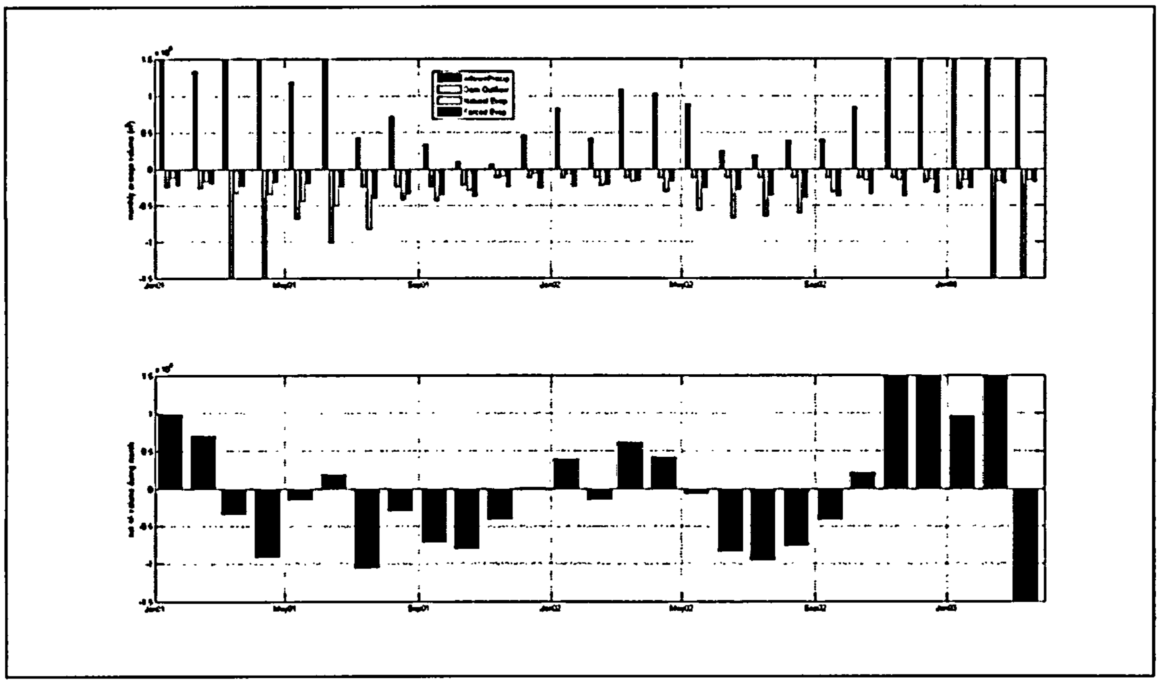

Figure 15 Historical Water Fluxes (NAPS units operating)

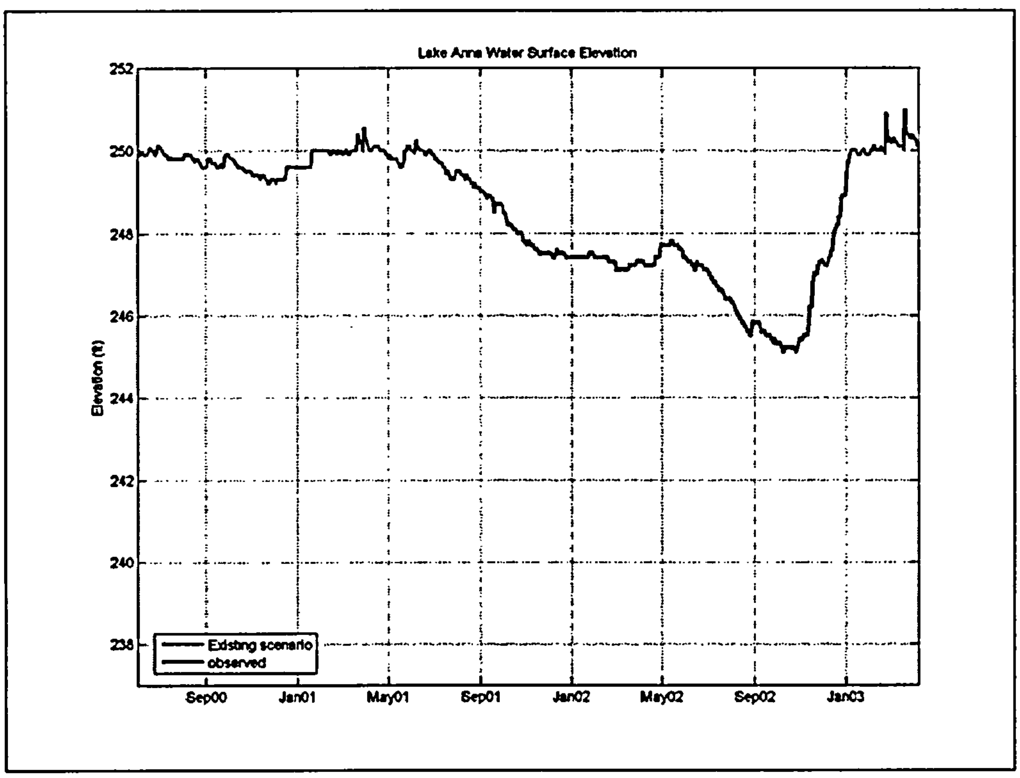

Figure 16 Water surface elevations observed (NAPS units operating)

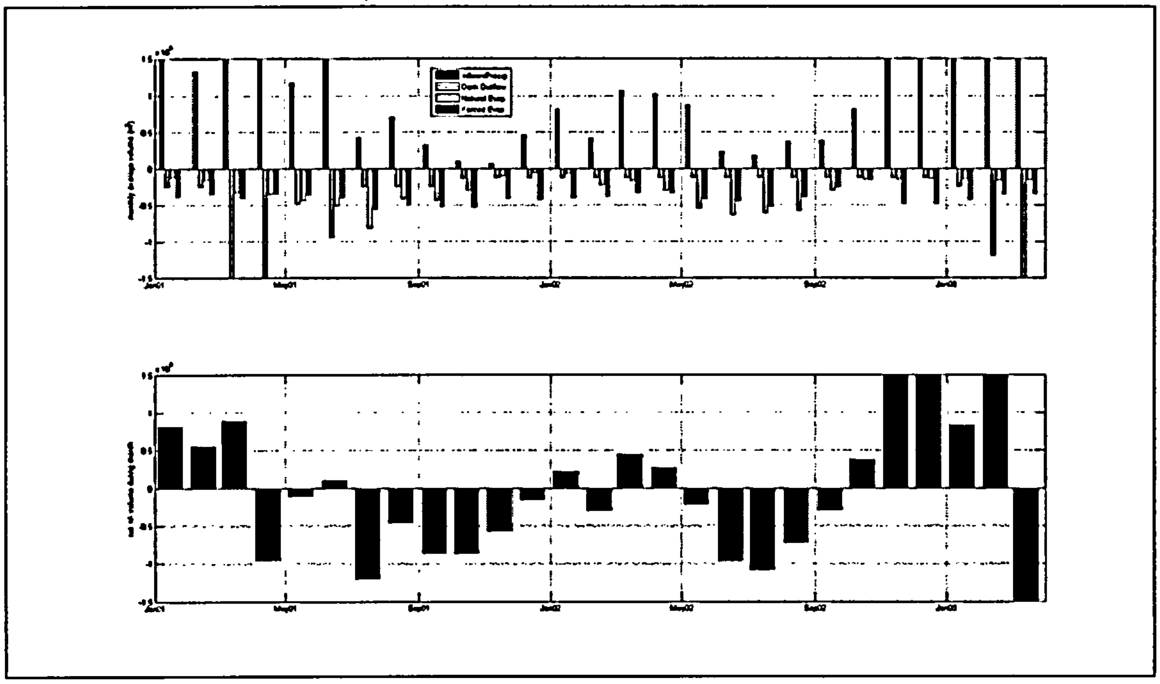

Figure 17 Evaporation fluxes Unit 3 once-through

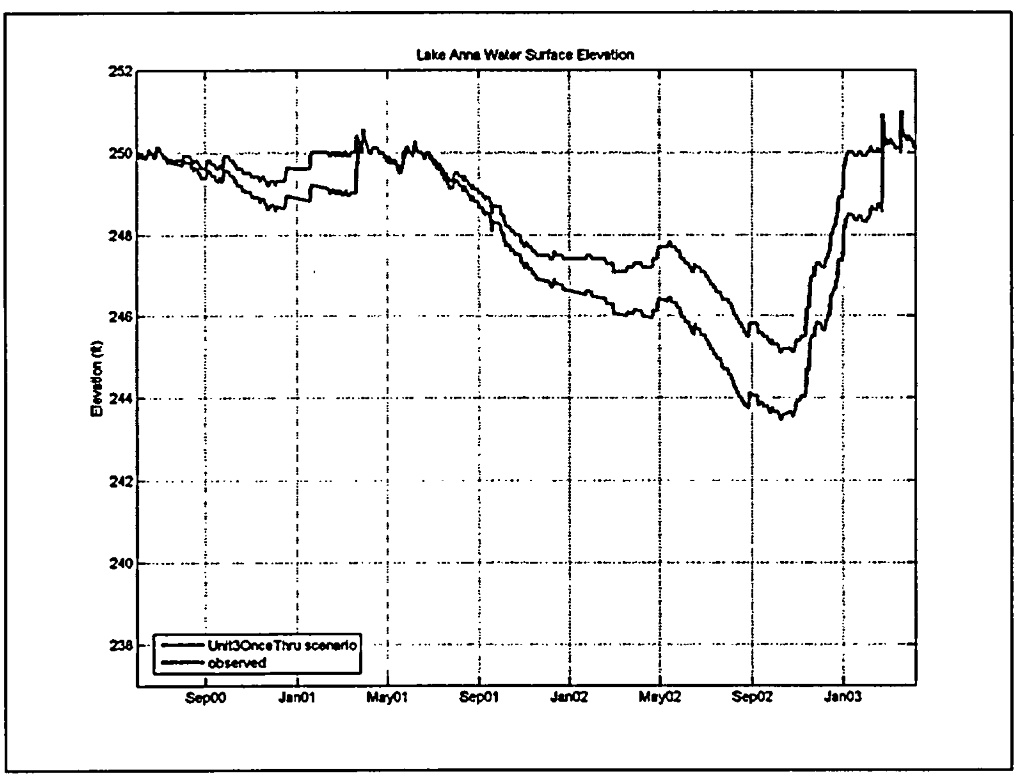

Figure 18 Water surface elevation Unit 3 once-through

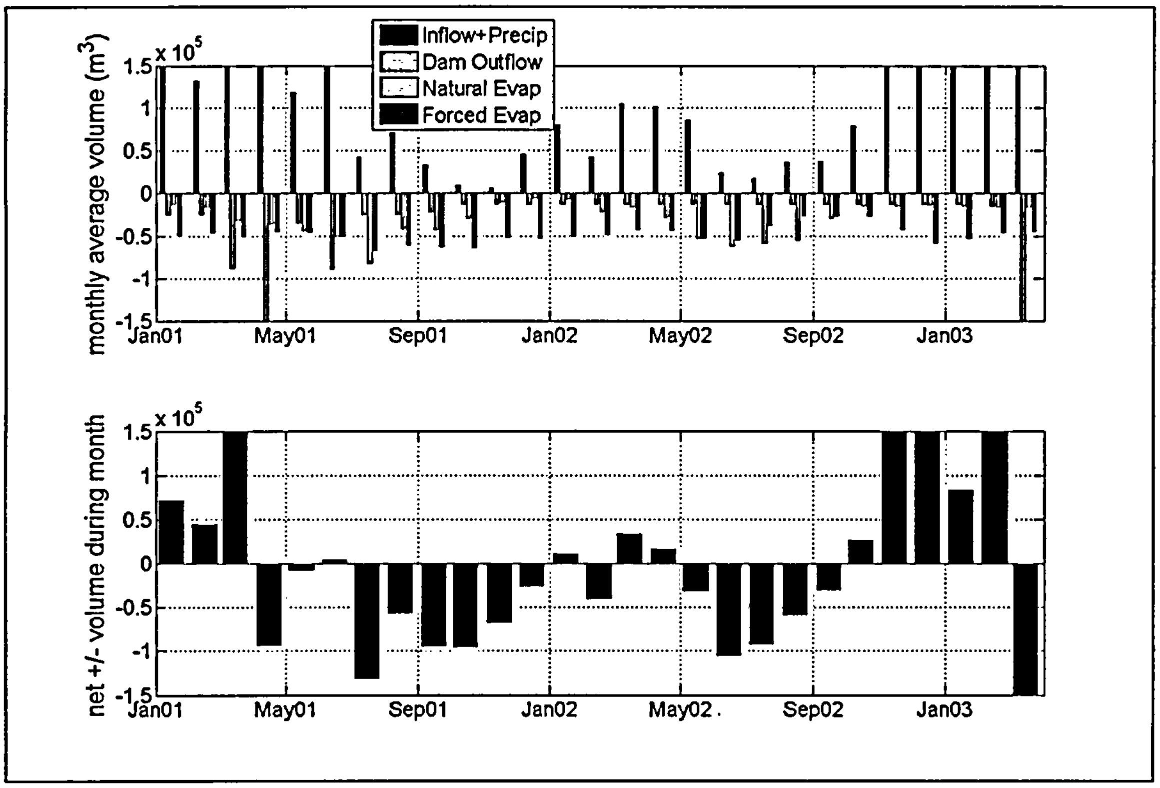

Figure 19 Evaporation water fluxes Unit 3 cooling tower

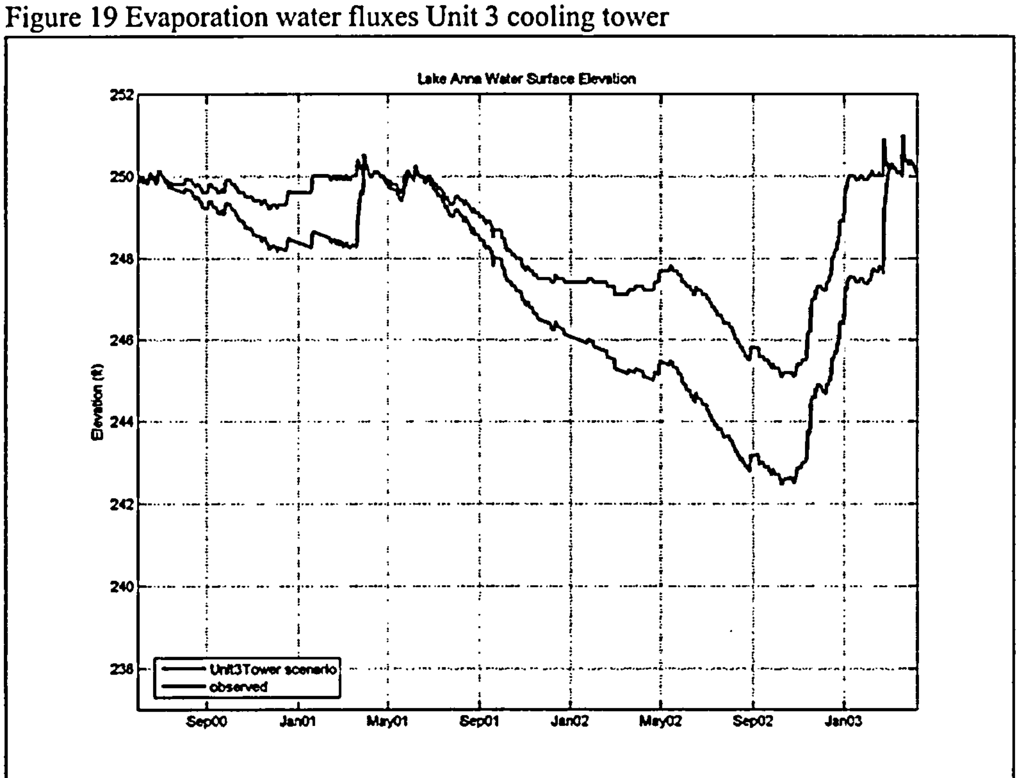

Figure 19 Water surface elevation cooling-tower Unit 3