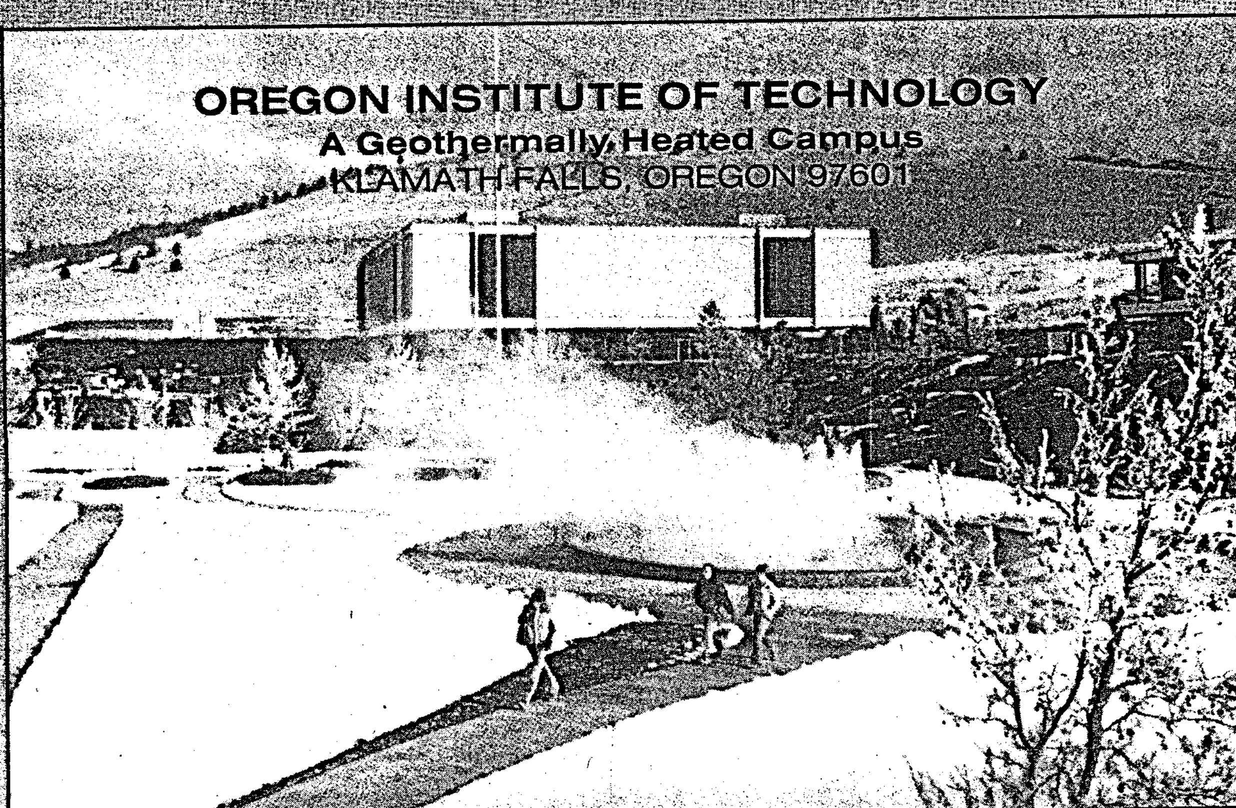
GEO-HEAT CENTER



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Performance Evaluation of Ormat Unit at Wabuska, Nevada

July 1986

NOTICE

This work was a cooperative effort of TAD's Enterprises, Ormat Systems Inc., Sierra Pacific Power Company, Electric Power Research Institute, Idaho Power Company, Bonneville Power Administration and the Geo-Heat Center at Oregon Institute of Technology.

The report and the Geo-Heat Center's efforts were supported under Oregon Department of Energy agreement L50002 and USDOE grant DE-FG51-79000077. Instrumentation for the Ormat binary generator was provided by Sierra Pacific Power Company under an agreement with Electric Power Research Institute.

Principal author of the report was Gene Culver, with a great deal of assistance in computation and analysis by Kevin Rafferty and Paul Lienau.

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1. Summary

Three nominal 24 hour tests under summer, winter and spring weather conditions, were run on an Ormat geothermal binary power generation machine. The machine, located at TAD's Enterprises in Wabuska, Nevada is supplied with approximately 830 gpm of geothermal water at 221°F and has two spray cooling ponds. During the tests, temperature, pressure and flows of geothermal water, freon, cooling water and instantaneous electrical production were recorded hourly.

At least once during each test, energy consumption of the well pump, freon feed pump and cooling water pumps were made. These parasitic loads were assumed to remain fairly constant during each test and, in fact, were the same during each of the three tests. Parasitic loads were: 55 kW at the machine itself for the feed pump and oil pump, and 186.6 kW for the geothermal brine and cooling water pumps.

Power output of the machine is limited by spray pond capacity. Net output ranged from 410.2 kW during summer conditions when cooling water was 65°F to 610.4 kW during winter conditions when cooling water was 55°F. Cooling water temperature during the summer test was abnormally high due to increased brine makeup to the cooling ponds. Under normal summer conditions, net output should be higher.

Problems with the flow meters used to measure brine, freon and cooling water flows prevented accurate thermodynamic analysis of the machine. We believe the cooling water flow rates to be fairly accurate. Brine flow

rates measured were on the order of 4 to 5% high and freon flow rates were 5% or more too high. Using these assumptions, net resource utilization ranged from 1.005 Whr/lb during the summer test to 1.55 Whr/lb during the winter test.

Spray pond performance averaged 63% for the fall and winter tests. Average approach temperature was 11°F, considerably higher than a typical good pond approach of 4-6°F. During periods of low humidity and light winds, performance improved dramatically.

Availability of the Ormat unit itself during the eight month test period was generally good, averaging 95.5%. Overall system availability, including well pumps, cooling system and electric grid was somewhat less - averaging 83%. The lowest monthly system availability of 63.8% was the result of a pump failure during bad weather and inability to get replacement parts to the site. Power sales for the 12 month period of April 1985 through March 1986 amounted to 2809 MW hours, for a capacity factor of 77.5%. Capacity factors during cold weather can exceed 100%. For example, December was 101%, even though availability was only 86.6%.

The largest number of faults have been due to electric grid fluctuations. These are usually of very short duration and the unit was usually restarted within 15 minutes. Other problems noted during the period seemed to be the result of over heating in the generator, circuit breakers and main feeder wiring.

TAD's personnel report that the machine was easy to operate and to perform scheduled maintenance on.

2. Introduction

This is the report of a program to monitor and evaluate the operation of a small geothermal binary power plant. The program was a joint effort of Sierra Pacific Power Company (SPPC), Idaho Power Company (IPC), Electric Power Research Institute (EPRI), Oregon Department of Energy (ODOE), Ormat Systems Incorporated (Ormat), TAD's Enterprises (TAD's) and the OIT Geo-Heat Center (OIT). The plant monitored and evaluated was a 600 kW Ormat binary machine owned by TAD's and located at Wabuska, Nevada.

SPPC coordinated the program and contracted with EPRI for funding to purchase test instrumentation. SPPC, IPC, Ormat and OIT provided support for carrying out the tests. TAD's provided the machine, allowed personnel on site to perform the tests and provided operational history. OIT, under contract to ODOE, assimilated test data and prepared the final report. ODOE funding was provided through a larger ODOE grant (DE-FG07-79RO00077) from the US Department of Energy.

3. Objectives and Approach

The objectives of the test program were:

1. To monitor the performance of the system as a whole and of each subsystem, i.e. production well and pump, binary machine and cooling ponds.

2. Perform energy balance calculations and to compare the results with predictions of a computer program.

3. Provide TAD's with suggestions for improving the performance of the total system or subsystems, particularly the spray cooling pond.

4. Provide operational data that could be of value in future binary power generation installations.

The testing program consisted of monitoring system operation during three nominal 24 hour test periods at different ambient weather conditions; summer, fall and winter. At one hour intervals, records of temperature, pressure and flow rates of geothermal fluid, binary fluid and cooling water were made. Also recorded were instantaneous electrical energy production and running time of pumps in order to obtain net electrical energy output. It was assumed that the parasitic load pumping energy for the well, binary fluid and cooling pond would remain relatively constant during the 24 hour test.

After the tests, energy balance calculations were made and plots made of electrical output, cooling water temperature, enthalpy out at the expander and turbine generator efficiency. These calculations were made in order to verify that the test records and procedures were essentially correct.

Further analysis of the system was performed to obtain second law efficiencies using the exergy analysis method proposed by DiPippo and Marcelle (Geothermal Resources Council Transactions, Vol. 8, August 1984).

4. System Description

The system at TAD's, like all binary power generation systems, has three major subsystems; the production well and pump, the binary machine and the cooling system. The Ormat binary machine is skid mounted and consists of evaporator, turbine/ generator, condenser, binary fluid feed pump and associated controls system. The cooling system, in this installation, is the spray cooling ponds. Figure 1 shows a simplified schematic diagram of the system.

Production Well and Pump

The well was drilled in 1959 to a total depth of 350 feet with 12 inch outside diameter casing to total depth. Bottom hole temperature was reported at 221°F.

A Hughes Centrilift downhole pump was installed late in 1983. The pump is a Series 875 Model 1 P, Type 1 B - 700, with four stages, driven by a Series 544, Model GMB, 100 hp motor. The pump was hung on 7 inch outside diameter tubing with the pump inlet originally at 285 feet. The pump is rated at 700 gpm at 353 feet total dynamic head.

A pump test performed by Geothermal Development Associates (GDA) in 1984 indicated a drawdown of 246 feet at 754 gpm and 214 feet at 729 gpm. The air line to measure drawdown installed with the pump was found to be

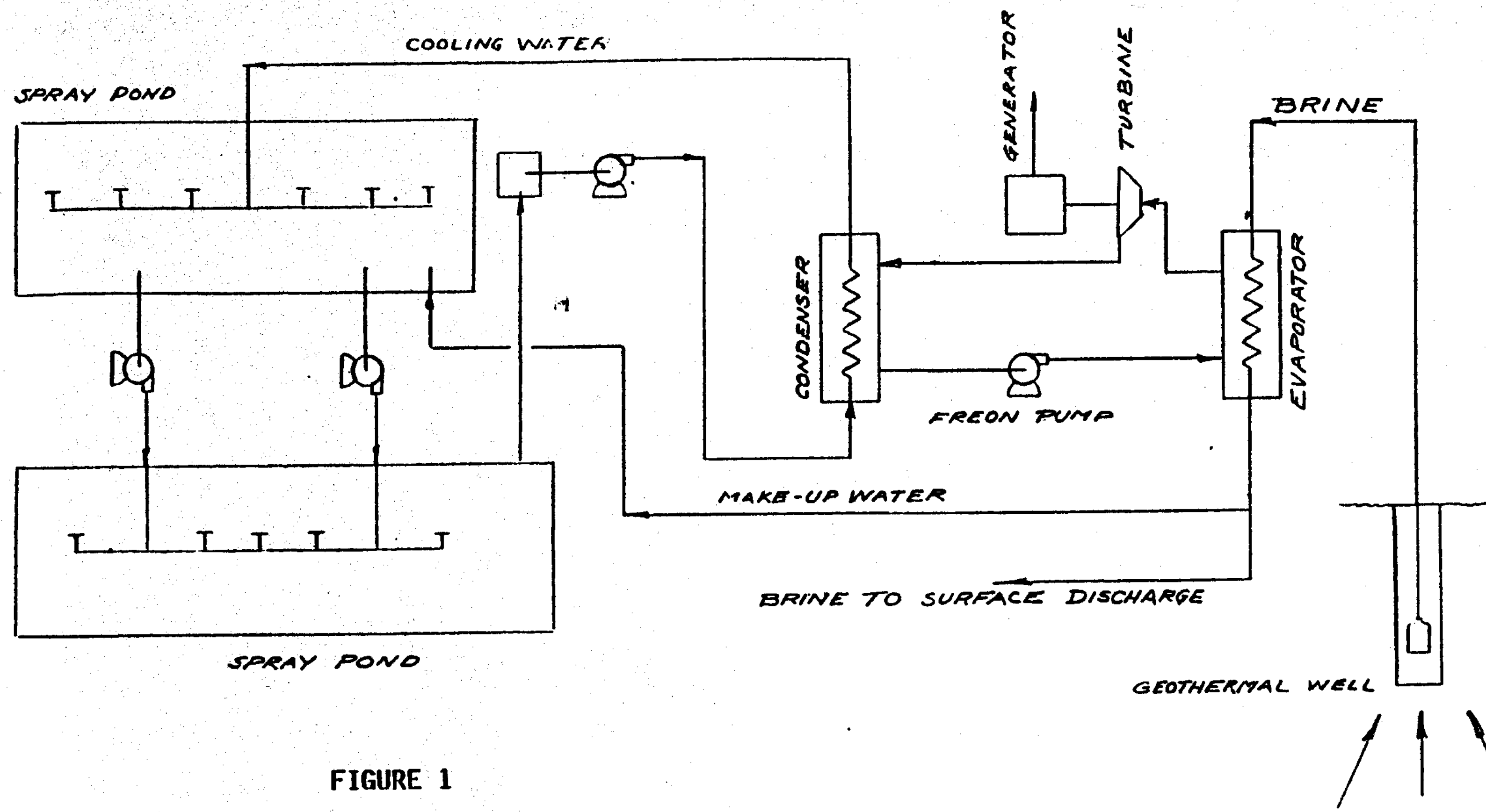


FIGURE 1

Simplified Schematic Diagram
of the System

inoperative during the current first two tests due to corrosion. This prevented measurement of drawdown during these tests.

Just prior to the third test a cable seal failure necessitated pulling the pump, and a new bubbler tube was installed with the pump allowing the pumping level to be obtained in the third test. The pump inlet was lowered 24 feet, at that time, to 309 feet below the wellhead flange.

During the third test, the pumping level remained constant at 208 feet with an indicated flow of 845 gpm. Although this seems to indicate increased well productivity since the GDA test, it is now known that TAD's well is affected by neighboring wells and there are no records of neighboring well's flow rates during either GDA's test or our tests. It is also believed that the flow meters currently used indicated flows higher than they actually were.

Piping from the well to the binary unit is approximately 500 feet of direct buried Schedule 30, 8 5/8" OD steel. Discharge from the unit was through approximately 400 feet of Schedule 30, 8 5/8" OD steel to an open ditch. The surface discharge to the ditch is routed to a neighboring aquaculture facility and used for growing prawns and catfish. During December, between the second and third tests, a pipeline was installed to carry water to the aquaculture facility.

Make-up water for the cooling ponds was taken from the discharge line about 15 feet before discharge to the ditch. Make-up flow is manually controlled by a valve at that point and with a valve at the end of the discharge providing back pressure to the line. Make-up water is routed to a small precooling spray pond and then pumped to the main cooling ponds. Make-up water flow is provided as required based on observation of the cooling pond level, and usually amounts to about 200 gallons per minute. Pressure on the discharge line, measured at the evaporator outlet, varied from a high of 96 psi when filling the spray pond to a low of 4 psi with normal make up flowing. This pressure affects the total dynamic head on the brine pump and therefore the brine flow.

Binary Machine

The binary unit at TAD's was built in 1982. It was one of the first of the larger series of geothermal/industrial process heat recovery units to be manufactured by Ormat. The unit is of modular construction, the entire machine including evaporator and condenser being contained in an 8' X 8' X 40' open box frame. The unit was originally designed to operate as a waste heat recovery unit on Freon 11 with a single stage impulse turbine. That application failed to materialize. For operation at the lower temperature available at TAD's, the unit was modified to operate on Freon 114. Although the machine is a nominal 600 kW unit, it has an 800 kW generator.

More than one approach was considered in optimizing the system design. For example, one option is to extract heat from a greater mass flow rate of resource. Using this approach the geothermal fluid at TAD's could, for example, be cooled from 221°F to approximately 203°F. This would allow a higher vaporization temperature, and a corresponding increase in Carnot efficiency, at the expense of an increased resource flow rate.

The approach taken with the modifications to the Ormat unit operating at TAD's was to optimize the system to cool the resource to approximately 167°F, therefore extracting the same amount of heat as the first method, but using one third the geothermal resource flow rate. This lowers the Carnot efficiency, since the working fluid vaporizing temperature will necessarily be lower; however, the electrical power output per unit mass of resource is increased and the brine pumping requirements are lower.

The equipment modifications to the unit included a change of working fluids from Freon 11 to Freon 114. Modification of the vaporizer heat exchangers, to change the configuration from the original two passes to four passes, reduced the flow rate of brine through the exchanger about 50%. The turbine wheel was changed in order to take advantage of the increased working fluid flow. The capacity of the working fluid feed pump was increased, as was the rating of the feed pump motor. In addition, a cooling fan was added to the power control cabinet, since it had been originally intended for installation in an air conditioned control room.

In order to accommodate a range of operating conditions, the turbine inlet manifold is divided into three sections. During start up a 4" throttling valve (V_1) and associated piping supply working fluid flow to nozzles around 45 degrees of the turbine inlet, thus providing a 'soft' start. An 8" valve (V_2) and piping supply working fluid flow to nozzles around an additional 225 degrees. This valve is normally open during operation and supplies working fluid to the turbine under low power conditions, i.e. reduced geothermal flow or high cooling water temperatures. A 6" valve (V_3) and piping supply the nozzles around the remaining 90 degrees of turbine manifold and is opened when full geothermal flow is available and cooling water temperatures are low, thus providing full power to the turbine. This arrangement provides power control while maintaining near optimum nozzle conditions under varying working fluid flows, varying temperature and pressure differential conditions. In the unit at TAD's, the 4" valve is pneumatically controlled by evaporator pressure sensors. The 6" and 8" valves are solenoid controlled. In newer models of these machines, the valves are computer controlled.

The turbine power and, therefore, generator output, appears to be limited by the cooling pond capacity. During warm weather operation, 8" valve V_2 is open providing freon vapor flow to 225 degrees of the turbine inlet manifold. When the condenser can handle the additional flow, 6" valve V_3 is opened, providing additional output. Valves V_2 and V_3 are electrically controlled by switches located in the control panel. When the operator notes cooling water outlet temperature is sufficiently low (about 85°F), a valve is opened. If the additional flow causes cooling water outlet temperature to rise above about 88°F, the valve is closed.

Cooling System

As originally installed, the cooling system consisted of a single spray cooling pond 400' X 125'. Cooling water was pumped from one corner of the pond by a PACO 50 hp pump. Cooling water flowed through approximately 500 feet of buried 12 inch PVC pipe with a steel pipe section at both the pump outlet and condenser inlet. From the condenser, water flowed back through a similar 12 inch buried pipe and to the pond at the center of the 400 foot dimension. Desired cooling water flow rate was 2500 gpm. The spray manifold consisted of a single length of 360 feet of 12 inch steel pipe supported three feet above water level. The spray system consisted of 24 sets of five 1 1/2 inch CX-30 nozzles each, mounted at the center and ends of 2 1/2 inch, 10 foot long steel pipes. Make up water entered at a corner of the pond through a four inch pipe terminated with a similar nozzle arrangement. See Figure 2. This was the pond configuration when the site was first visited in February 1985.

Several problems with the cooling system were noted during warm weather operation;

1. Cooling capacity was too low for efficient operation of the system.

2. Friction loss in the piping was excessive.

3. Make-up water "short circuited" from make-up spray to circulating pump, raising pond outlet temperature (condenser inlet) above the average pond temperature.

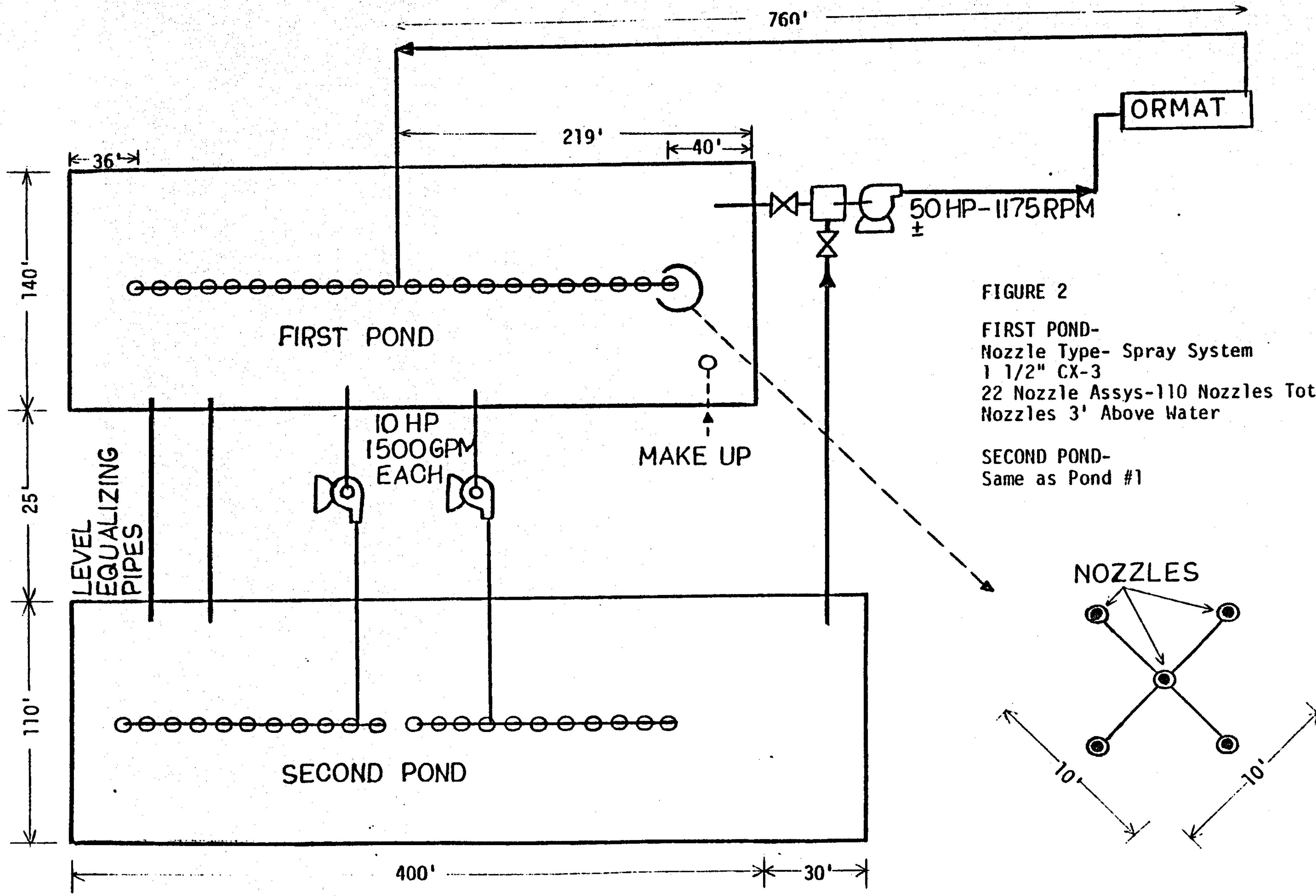


FIGURE 2

FIRST POND-
Nozzle Type- Spray System
1 1/2" CX-3
22 Nozzle Assys-110 Nozzles Total
Nozzles 3' Above Water

SECOND POND-
Same as Pond #1

During the summer before the tests were started, several changes were made to the cooling system.

1. A second cooling pond was constructed adjacent to the first. This pond was equipped with a manifold and spray nozzles duplicating those in the first pond. Two 10 hp 1500 gpm Aurora pumps were installed to pump water from the first pond to the sprays in the second. A new cooling pump inlet box, piping and valves were installed to take water from the second pond. Two 8" PVC pipes between the ponds equalize water levels. Make up water continues to go to the first pond. This arrangement increases the cooling capacity and eliminates the short circuiting of make up water.

2. Additional cooling water piping of the same size was installed parallel to the original. This piping is Y'd at the pump outlet, condenser inlet and outlet and at the inlet to the spray manifold at the first pond. Typical cooling water pressures before and after modification were:

	Before	After
Pump outlet	24 psi	21 psi
Cond. inlet	17 psi	17 psi
Cond. outlet	15 psi	11 psi
Spray manifold	6½ psi	7 psi

The effect of the second pond on condenser inlet temperature is difficult to quantify because of lack of data before the addition, but appears to have reduced condenser inlet temperature by at least 15°F under most conditions.

4. Instrumentation and Data Acquisition

As originally envisioned, the tests and instrumentation were set up so that each subsystem; production well and pump, binary unit, and cooling system, could be monitored and their efficiency and operating characteristics readily calculated. Figure 3 shows a detailed schematic of the system and the instrument test points. Table 1 lists the instrumented parameters and their nominal operating values. Appendix A provides a list of instrumentation at the points and instrument data. As can be seen on Figure 3, temperatures, pressures and flows were measured at the inlet and outlet of each subsystem, i.e. evaporator and condenser inlet and outlet. Electrical energy production, electrical energy use (for parasitic loads), wind speed and direction, and wet and dry bulb temperature were also monitored.

During the tests, most of the parameters measured were manually recorded hourly. Additionally, temperature was recorded on a multipoint recorder at T_2, T_3, T_4, T_6, T_7, T_8 and T_9 providing a continuous record of these values during the 24 hour tests.

Continuous weather data were provided from a portable weather monitor, provided by IPC, that was installed at the northwest corner of the cooling ponds, . Wind speed and direction, temperature and relative humidity were sampled every two seconds. A Campbell Scientific CR21 Data Logger reduced the samples providing 15 minute averages of wind speed, wind direction, temperature and relative humidity, maximum wind speed, time of maximum speed and minimum and maximum temperatures. This information was recorded

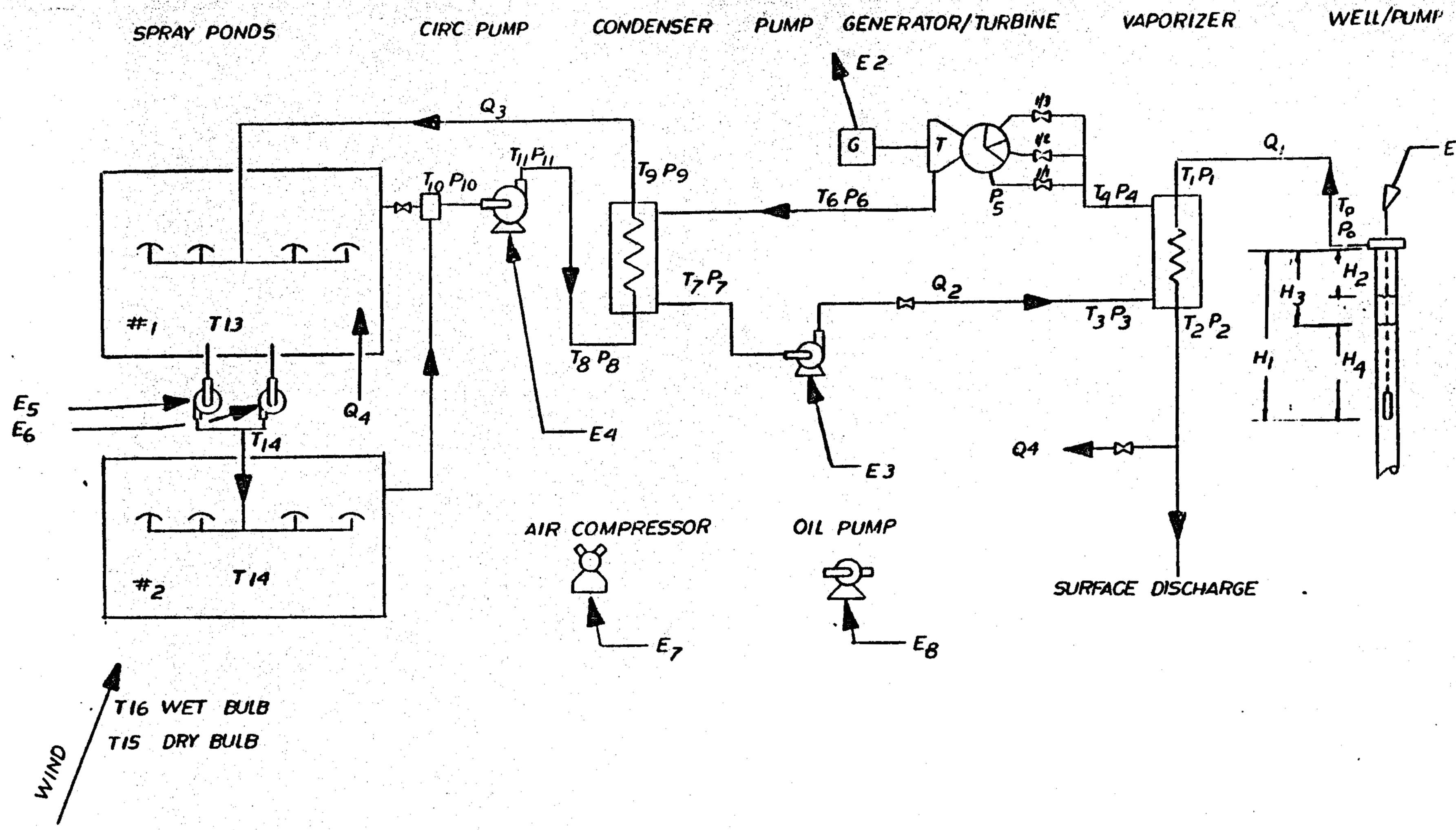


Figure 3

ORMAT UNIT
WABUSKA, NV
2-22-86 WEB

TABLE 1

Instrumented Operating Parameters

Production Well & Pump		
E_1	Well Pump Power	105 A 464V (measured ahead of step up transformer)
H_1	Pump Setting	285 ft tests 1 & 2, 309 ft test 3
H_2	Static Water Level	Not Avail.
H_3	Pumping Water Level	208 ft test 3, assumed same for 1 & 2
H_4	Positive Pump Head	77 ft tests 1 & 2, 101 ft test 3
T_0	Well Head Temp.	223°F
P_0	Well Head Pressure	210 - 96 psi
Binary Unit		
Q_1	Brine Flow Rate	621 - 894 gpm
T_1	Brine Temp. into Evaporator	221°F
P_1	Brine Press into Evaporator	17 - 96 psi
T_2	Brine Temp. out of Evaporator	160 - 173°F
P_2	Brine Press out of Evaporator	10 - 87 psi
Q_2	Freon Flow	360 - 607 gpm
T_3	Freon Temp. into Evaporator	77 - 99°F
P_3	Freon Press. into Evaporator	133 - 153 psi
T_4	Freon Temp. out of Evaporator	186 - 195°F
P_4	Freon Press. out of Evaporator	113 - 138 psi
P_5	Freon Press. at Nozzle Block	24 psi (test 1 only)
T_6	Freon Temp. Turbine Outlet/ Condenser Inlet	130 - 141°F
P_6	Freon Press. Turbine Outlet/ Condenser Inlet	17 - 35 psi
T_7	Freon Temp. Condenser Outlet/ Feed Pump Inlet	77 - 96°F
P_7	Freon Press Condenser Outlet/ Feed Pump Inlet	24 - 30 psi
T_8	Cooling Water Temp. Cond. Inlet	54 - 78°F
P_8	Cooling Water Press. Cond. Inlet	17 - 20 psi
T_9	Cooling Water Temp. Cond. Outlet	68 - 98°F
P_9	Cooling Water Press. Cond. Outlet	10 - 11 psi
E_2	Generator Output	
E_3	Feed Pump Power	77 A @ 480 V
Q_3	Cooling Water Flow	1905 - 2315 gpm

Cooling System

T_{10}	Cooling Water Temp. Pond Out/ Pump In	54 - 78°F	
P_{10}	Cooling Water Press. Pond Out/ Pump In	0.43 psi	
T_{11}	Cooling Water Temp. Pump Outlet	54 - 78°F	
P_{11}	Cooling Water Press. Pump Outlet	21 psi	
T_{12}	Cooling Water Temp. in Spray	50 - 76°F	Measured at base of spray.
T_{13}	Avg. Temp. 1st Pond	56°F	Avg. of 6
T_{14}	Avg. Temp. 2nd Pond	54 - 61°F	Avg. of 6
T_{15}	Dry Bulb Temp.	30 - 98°F	Measured near Ormat unit.
T_{16}	Wet Bulb Temp.	29 - ?°F	Measured near Ormat Unit.
E_5	Transfer Pump 1 Power	13.5 A @ 460 V	
E_6	Transfer Pump 2 Power	13.5 A @ 460 V	

on cassette tapes and reduced to printed form by IPC. The weather monitor started operation July 10th and ran continuously throughout the seven months except for the three days during the first test when the tape was inoperative and between about November 1st and November 17th when night time data was erroneous but day time data was correct. The exact cause of this has not been determined.

Electrical energy use for parasitic loads E_1 and E_3 through E_6 were measured using a clamp type ammeter and clip on voltmeter at some time during each of the 24 tests. It was assumed that these loads would be constant during system operation. Power to the 1 hp expander oil pump E_8 and the instrument air compressor E_7, which runs only intermittently, were not measured. Power for the feed Pump E_3 and compressor E_7 is supplied from the control cabinet circuitry between the generator and output meter. The output meter therefore measures E_2 net power from the modular unit.

Cooling pond temperature T_{13} and T_{14} was measured using mercury in glass thermometers suspended approximately 6 feet out from the bank. Temperatures were taken at six locations in the first pond and five locations in the second. Temperature in the spray was taken by suspending cans on a trolley in the spray at two locations, pulling the cans quickly to the bank and measuring the temperature. Temperature at the cooling pump inlet and the pump positive suction head were measured at the pump head gate box.

Wet bulb T_{16} and dry bulb T_{15} air temperature were also measured with mercury in glass thermometers. These measurements were taken near the binary unit about 500 feet from the ponds so that measurements would not be affected by the ponds.

Electrical energy output during the tests was measured by counting turns and timing five or more turns of a kilowatt hour meter at the control panel with a stop watch. Shortly after the first test TAD's installed a recording kilowatt hour and power factor meter, and this was used as a cross check on electrical output during the second test. This meter was not available during the third test.

It appears that electrical output measured by counting turns on the kWh meter at the Ormat unit may be about 10 kW high. For instance, at 1230 and 1330 hours, March 6th unit output as recorded from the kWh meter was 562 kW. Major parasitic loads (measured within several hours and assumed to be fairly constant) totaled 187 kW and site output measured at Sierra Pacific's bi-directional kilowatt hour meter was 370 kWh during the hour. This leaves 12 kWh unaccounted for. Some of this was due to lights and equipment operation in the maintenance shop, office lighting, etc. However, similar discrepancies were noted between the kWh meter and the recording kW and power factor meter which was available during the second test. During that test there were differences ranging from 0 to 18 kW with the average difference 9 kW. The cause for this discrepancy could not be determined; however, it is very small, amounting to only 1.2 to 1.4% of generator output. It therefore appears that site loads and output balanced within the accuracy of our instrumentation.

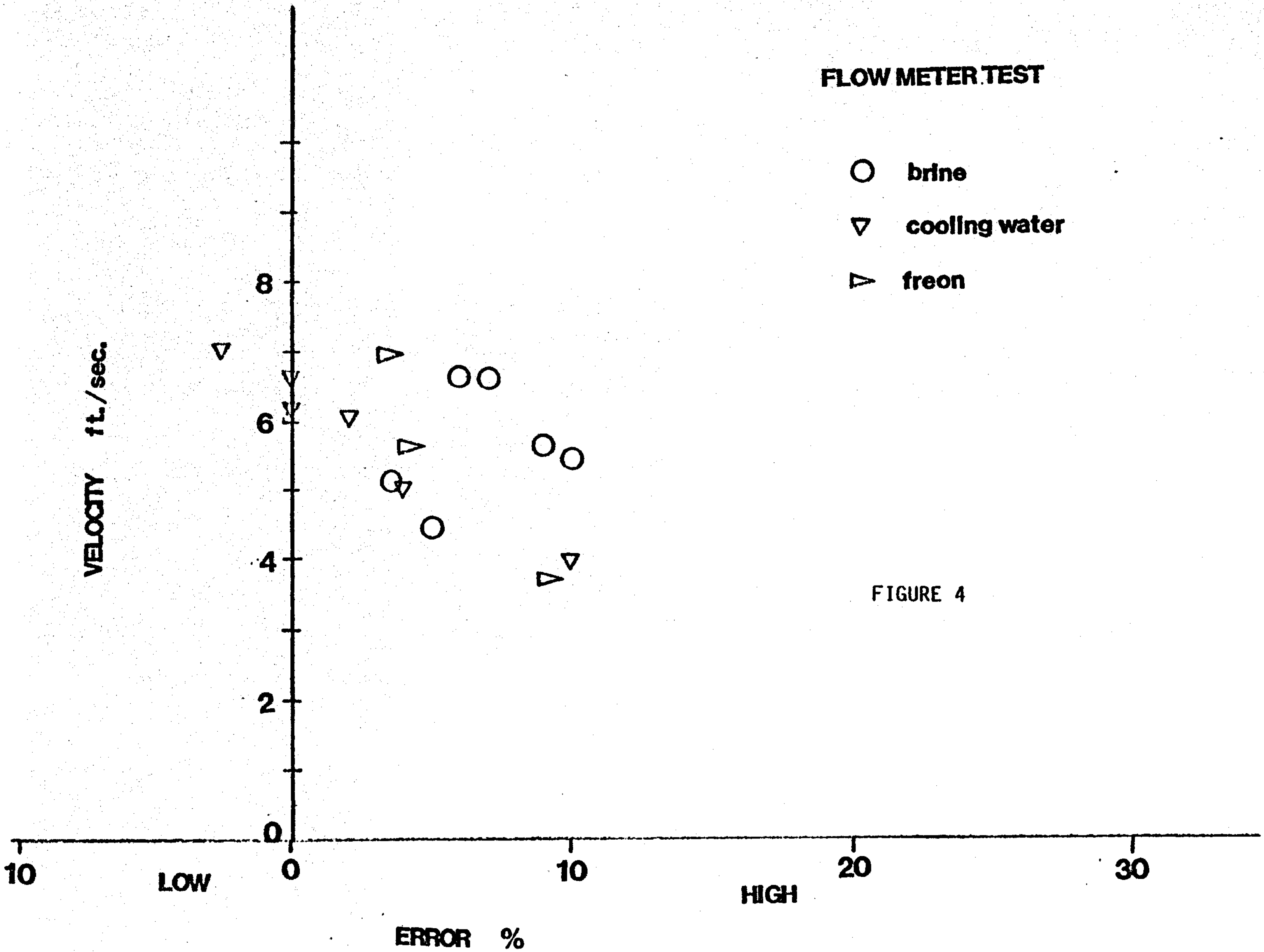

FLOW METER TEST
brine
cooling water
freon
VELOCITY ft./sec.
0
2
4
6
8
10
LOW
0
10
20
30
HIGH
ERROR %

FIGURE 4

During the fall test it was noted that during a four hour period late in the test, brine flows were low. Subsequent heat balance calculations showed the flow meter readings to be in error. The flow meters were taken to the University of California Water Resources Lab at Davis for calibration. Although the calibration runs provided somewhat scattered results, it appeared the meters gave readings 2½ to 10% high.

Flow meters were calibrated using the time and known volume method. The flow meters indicate flow rate and have a totalizer which electronically multiplies flow rate by time to arrive at total flow. The calibration facility has a series of known volumes where water level is measured electrically and time is measured to the nearest second. Typical runs were 4,300 gallons in times ranging from 240 to over 900 seconds, with volume and time noted at three points during the run. Total flow for the test and flow rate were compared and a percentage error calculated. Results of the calibration for the electronics/sensor combinations used to measure brine, cooling water and freon are shown in Figure 4. Note that there appears to be an increase in error at the lower velocities. Piping sizes on the Ormat machine were such that velocities were in the 4.8 to 6.5 ft/sec range, where the average error was about 4%.

At TAD's we believe the measured cooling water flows are probably fairly accurate since calibration runs indicated that the electronics/sensor combination appeared to be the most accurate of the three at the velocities in the cooling water piping and there should be sufficient particles in the water for good sonic echos. Measured brine flows are probably about 6-7% high (50-60 gpm) and there should have been sufficient particles and turbulence to obtain good echos. The measured freon flows are more in doubt. There is a large variation in calculated heat balances and there may not be enough particles in the freon to obtain steady echos.

Effects of Measurement Errors

In order to check recorded data, programs for hand held TI 59 calculators were developed. The programs calculate enthalpies, and using the calculated enthalpies in and out of the turbine and refrigerant flow, a value is calculated for heat out at the turbine. The same procedure is employed to determine heat in at the evaporator and heat out at the condenser. Theoretical feed pump work is calculated from flow rate and dynamic head.

On the brine and cooling water sides, flow rate and temperature change are used to calculate heat in and heat out respectively.

The heat balances on the two heat exchangers are then used as a check on the accuracy of the input data. The working fluid side value (in Btu/minute) is compared to the brine or cooling water side value (in Btu/minute) and the difference is determined. The difference is then divided by each of the original values to arrive at an error figure.

While it should be expected that some heat flow from the generator to the environment, and to or from the condenser (depending upon ambient temperature), will take place, error figures greater than a few percent indicate a problem with input data.

Table 2 presencs error information on the program's calculation of key system enthalpies. Note that using the program's calculated enthalpies resulted in errors of a few tenths of a percent.

In order to determine the serviceability of the program to changes in input data, a single data set from the fall test was selected at random. Seventeen groups, for a total of thirty-nine runs were made, each changing a single input value by 1°F, 1 psi or .1 ft/second. Table 3 summarizes the results of this test. The results indicate that an instrument error of 1%, 1 psi or 0.1 feet/second will result in calculated values being in error by about 2% or less except in the condenser. Since the cooling water temperature change across the condenser is relatively small and the mass flow rate is high, an error of 1°F will result in a 5.4% error in calculated enthalpies.

In light of the problems noted with the flow meters during the fall test and subsequent difficulties in calibration of these meters, it is important to note the machine performance accuracy was affected by errors in flow measurement. These errors will, in general, be higher than those caused by errors in other measurements. Also, one has more confidence in temperature and pressure measurements since these instruments are inherently less prone to develop trouble and were calibrated and/or checked before and after test runs. This will be discussed further under results of the second test where there were apparently errors in flow measurement. Unfortunately there appears to be no way it can be determined how much any of the tests were affected. Readers should keep in mind that stated results may be based on erroneous flows.

A summary of program output for the summer and fall tests is shown in Tables 4 and 5.

TABLE 2

Accuracy of Program Calculation of Key Enthalpies

Value	Temp.	Table Value	Program Calculation	Difference	Error %	% Error in Δh Turbine	% Error Δh Cond.
125.3 psig	190°F	97.960	98.008	+0.048	+0.05	+0.7	-
125.3 psig	180°F	95.900	95.938	+0.038	+0.04	+0.5	-
105.3 psig	190°F	98.770	98.744	-0.026	-0.03	-0.4	-
105.3 psig	180°F	96.762	96.674	+0.012	+0.01	+0.2	-
24 psig	130°F	90.948	90.942	-0.006	-0.007	-0.08	+0.009
24 psig	140°F	92.752	92.762	+0.010	+0.01	+0.13	-0.015
16 psig	130°F	91.231	91.240	+0.009	+0.009	+0.12	-0.014
16 psig	140°F	93.023	93.060	+0.037	+0.04	+0.04	-0.055
20.945	85°F	28.088	28.088	0	0	-	0
17.959	80°F	26.865	26.933	+0.068	+0.25	-	+0.11
15.167	75°F	25.651	25.778	+0.127	+0.49	-	+0.09
23.479	89°F	29.071	29.012	-0.059	-0.20	-	+0.09

Table 3

Run #1, +1°F in Temp.

Error in Temperature	+0.45%
Evaporator Δt Error	+1.72%
Evaporator Heat in Error	+1.72%

Run #2, +1° Brine out Temp.

Error in Temperature	+0.62%
Evaporator Δt Error	-1.72%
Evaporator Heat in Error	-1.72%

Run #3, +.1 Ft/Sec Brine Flow

Velocity Error	+2.02%
Evaporator Heat in Error	+2.02%

Run #4, +1°F Working Fluid in @ Evaporator

None

Run #5, +1 psi Working Fluid in @ Evaporator

None

Run #6, +1°F Working Fluid out of Boiler/in @ Turbine

Error in Temperature	+0.52%
Error Enthalpy	+0.21%
Error Δh Turbine	+2.74%
Error Δh Evaporator	+0.29%

Run #10, +1 psi Working Fluid out Evaporator/in @ Turbine

Error in Pressure	+0.85%
Error Enthalpy	-0.03%
Error Δh Turbine	+0.49%
Error Δh Evaporator	-0.05%

Run #11, +0.1 Ft/Sec Working Fluid Velocity

Error in Velocity	+2.13%
Error Heat in (Evaporator)	+2.123%
Error Heat out (Turbine)	+2.13%
Error Heat out (Condenser)	+2.13%

Run #12, +1° Cooling Water in @ Condenser

Error in Temperature	+1.89%
Error Cooling Water Δt	-5.4%
Error in Heat out (Cooling Wtr)	-5.4%

Run #13, +1°F Leaving Cooling Water Temperature

Error in Temperature	+1.40%
Error in CW Δt	+5.4%
Error in Heat out	+5.4%

Run #14, +0.1 Ft/Sec Cooling Water Velocity

Error in Velocity	+1.67%
Error in Cond. Heat out	+1.67%

Run #15, +1°F Temperature out °F Turbine/in @ Condenser

Error in Temperature	+0.74%
Error in Enthalpy	+0.20%
Error in Δh Turbine	-2.41%
Error in Δh Condenser	+0.28%

Run #16, +1 psi Turbine out Pressure/Condenser Entering Pressure

Error in Pressure	+3.13%
Error in Enthalpy	-0.04%
Error in Δh Turbine	+0.49%
Error in Δh Condenser	-0.06%

Run #17, +1°F Working Fluid Temp. out of Condenser

Error in Temperature	+1.29%
Error in Enthalpy	+0.87%
Error in Δh Condenser	-0.36%

Table 4

Summary of Summer Test Results

Brine Temp.	Cooling Water Temp.	Calculated kW out of Turbine	Machine Performance Index	Measured kW out of Gen.
221	79.0	513.5	8.2	no data
221	76.0	530.6	8.5	no data
221.5	77.0	491.4	8.5	no data
221.5	77.5	494.4	8.8	no data
222	77.0	471.2	8.9	no data
218	74.5	534.3	8.9	no data
222	75.5	536.5	9.0	no data
222	75.0	536.5	9.0	no data
222	74.5	540.9	9.4	no data
222	73.7	510.2	9.5	no data
221	73.0	564.8	9.5	no data
220	73.0	577.7	9.8	no data
221	72.2	549.5	9.7	no data
221	72.0	537.0	9.7	no data
221	70.0	577.4	9.9	no data
221	74.5	544.1	8.6	no data
221	72.5	558.7	8.7	no data
221	74.0	559.9	8.7	no data
221	77.0	496.2	8.9	no data
221	77.8	463.9	8.4	no data
221	78.8	466.0	8.5	no data
221	79.2	504.1	8.7	no data
221.5	79.5	507.3	8.8	no data
221.5	80.0	524.6	8.8	no data
221.5	78.8	508.6	8.8	no data
221.5	78.0	539.3	8.8	no data
221.5	76.0	517.0	8.8	no data
221	74.5	523.5	9.2	no data
221	74.0	526.9	8.0	no data
221	72.5	504.6	7.7	no data
221	71.0	525.6	8.0	no data
221	70.0	527.1	8.3	no data
221	68.5	557.6	8.7	no data
221	67.0	580.6	9.1	no data
221	66.5	586.6	10.5	no data
221	65.5	672.9	10.5	no data
222	65.0	647.2	10.0	no data
221.5	68.6	637.3	9.9	no data

Table 5

Summary of Fall Test Results

Brine Temp.	Cooling Water Temp.	Calculated kW out of Turbine	Machine Performance Index	Measured kW out of Gen.
220	53.5	627.7	10.3	646.3
221	54.5	604.3	10.3	640.5
220	55.5	667.7	10.1	638.2
220	56.0	630.1	9.9	631.6
220	56.5	622.8	9.7	629.8
220	56.0	623.6	9.8	630.7
220	55.0	621.6	9.9	631.9
220	55.8	584.2	9.5	631.6
220	55.8	603.6	9.7	631.6
221	55.5	617.1	9.8	634.2
221	55.0	604.8	9.9	637.3
221	54.5	608.9	9.9	638.9
220	55.0	551.2	9.0	641.2
220	54.0	513.8	8.8	645.3
220	53.5	595.7	10.2	649.9
220	53.0	573.8	10.3	652.1
220	52.0	591.7	10.3	655.1
220	52.0	636.0	10.4	661.7
220	52.5	603.7	10.4	663.8
220	52.0	630.2	10.7	665.4
220	51.5	687.3	10.7	663.3
221	52.0	688.0	10.6	659.2
220	53.0	667.9	10.4	653.1

6. Measured Performance

Summer Test

The summer test was scheduled for August 14, 1985. The binary unit had been operating normally for several weeks with only brief electrical nuisance trips due to grid voltage fluctuations. On August 12th, the underground power cable to the production well pump failed. The problem was located and repaired and the system went back on line late August 13th. The test started on schedule. On hand to take and record data were personnel from SPPC, IPC, Bonneville Power Administration (BPA) and OIT. Ormat personnel were there as observers and to assist with test instrumentation for the unit. TAD's personnel were performing their regular operational duties. The test started at 6 pm, August 14th and ended at 11 am, August 16th.

Due to the seepage and evaporation from the cooling ponds during the down time for repairing the power cable, the water level in the pond had lowered to the point where the cooling water pump was intermittently taking air due to the formation of a vortex over the inlet pipe. In order to correct this, approximately two thirds of the brine discharge flow was being delivered to the precooling system and ponds as make up. At 8 am, August 15th, this was increased to nearly all the discharge and was reduced to about one third flow at 2:30 pm that day. Make-up flow remained constant for the remainder of the test.

Since the brine discharge valve position affects the pressure head on the production well pump, as measured at P_1 and P_2, flow rates will change as the valve is opened or closed. These changes were readily apparent in the brine flow and pressures. As expected, other parameters quickly affected were brine temperature out T_2, freon temperature and pressure into the turbine T_4 and P_4, feed pump pressure P_3 and to a lesser extent, cooling water temperature out T_9 and feed pump pressure inlet P_7. Other parameters changed more slowly as the unit moved to a new equilibrium condition (see Figure 5). Obviously, introducing large amounts of hot brine into the cooling pond will raise the pond temperature, but also contributing were solar radiation, lack of any wind and ambient air temperatures approaching 100°F. No attempt was made to separate out these factors.

Unfortunately, the effect of varying geothermal water flows on electrical energy output could not be obtained. It had been assumed that a kilowatt hour meter mounted in the Ormat unit control cabinet was reading correctly. During the August test run, comparisons of calculated energy and measured energy did not agree. Subsequent to the test it was determined that the meter had been incorrectly wired and was giving erroneous readings. The meter was replaced on October 7 with one that had been tested in SPPC's meter shop and was available for the fall and winter tests.

Although the meter did not give accurate readings and was unstable, it did appear to follow trends. For instance, when the 6" turbine freon valve was opened, the indicated electrical output increased significantly (from 461 kW to nearly 500 kW) within two hours. Instability was to the extent the meter indicated fluctuations of as much as 60 kW at consecutive hourly

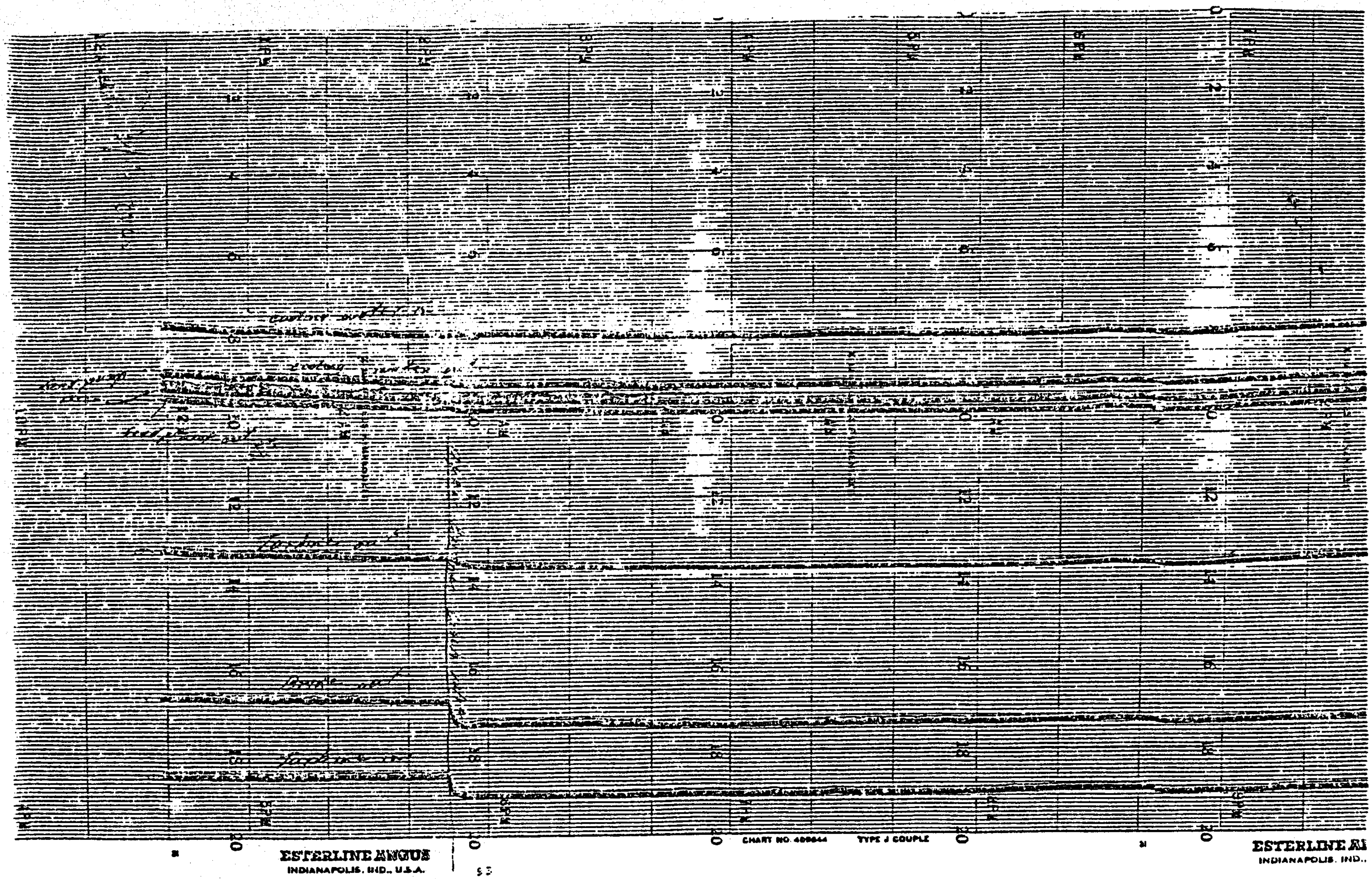


Figure 5

readings with no significant changes in any operating temperatures and pressures. Figures 6 and 7 are plots of electrical output versus entering cooling water temperature, and efficiency versus entering cooling water temperature respectively. Although the plots show a general trend, the data are so scattered they are of no value in assessing machine performance. Figure 8 shows the effect of a power change on brine freon and cooling water temperatures when the 6" turbine inlet valve was opened. Raw data from the summer test are contained in Appendix C.

Table 6 shows a computer printout of the available work analysis method applied to selected data points from the summer test. The points selected were before and after some change in operating conditions was made. Some of the flows have been adjusted to account for fluctuations in flow meter readings taken (averaged for the time conditions should have been constant) and all temperatures are from the multi point thermocouple recorder.

At 0800 on August 15th the machine was operating with only the 8" valve to the turbine inlet open and approximately two thirds of the brine flow going to the cooling ponds. At 0815 the 4" turbine inlet valve was opened and the brine discharge valve nearly closed, diverting almost all the brine to the cooling ponds. By 0900 the following results were noted.

Brine flow was decreased by approximately 20% with accompanying decrease in brine outlet temperature and a decrease in available exergy (energy available above a reference temperature - see Appendix C for explanation and sample calculation) at the evaporator. Evaporator efficiency, however, increased.

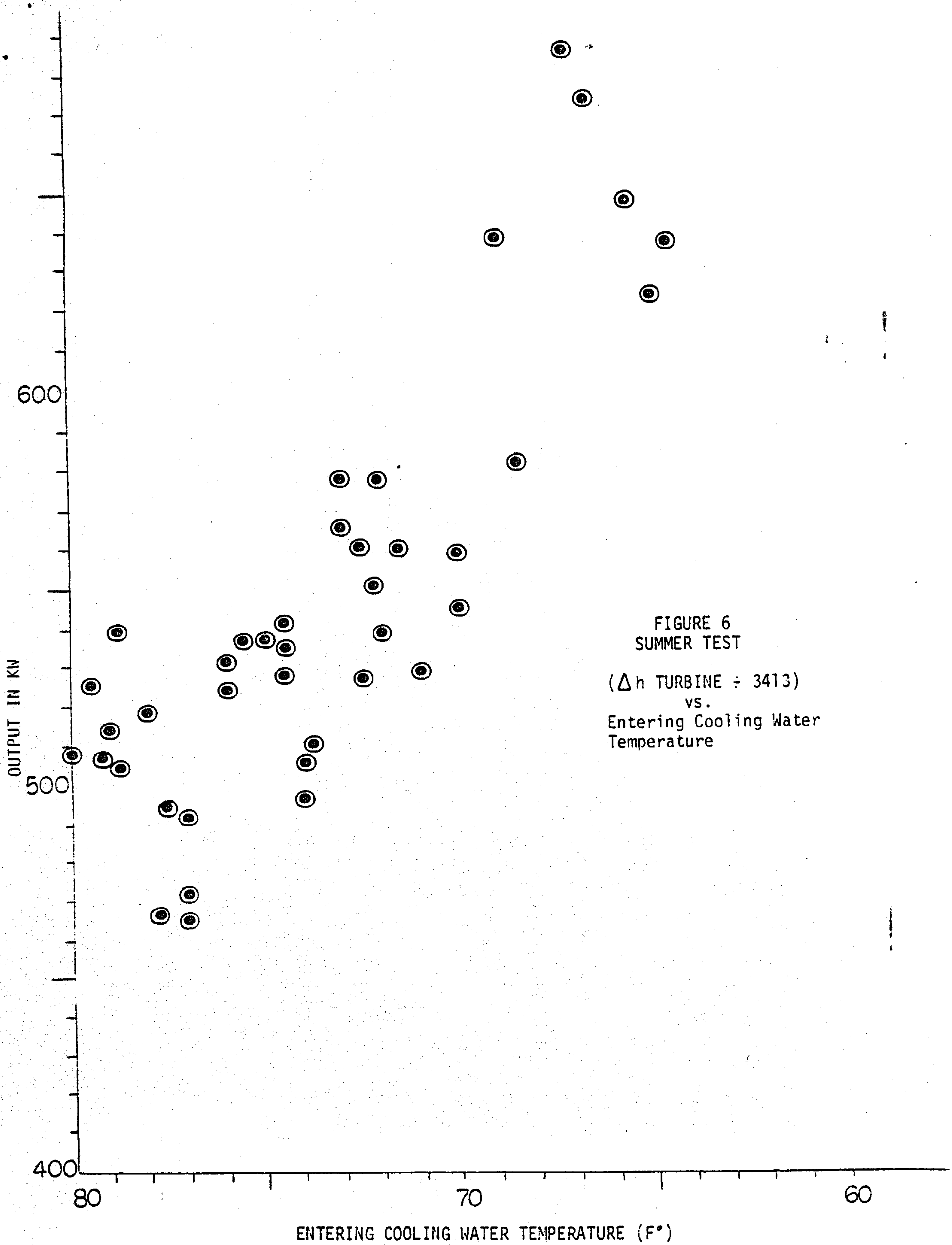


FIGURE 6
SUMMER TEST

(Δh TURBINE ÷ 3413)
vs.
Entering Cooling Water
Temperature

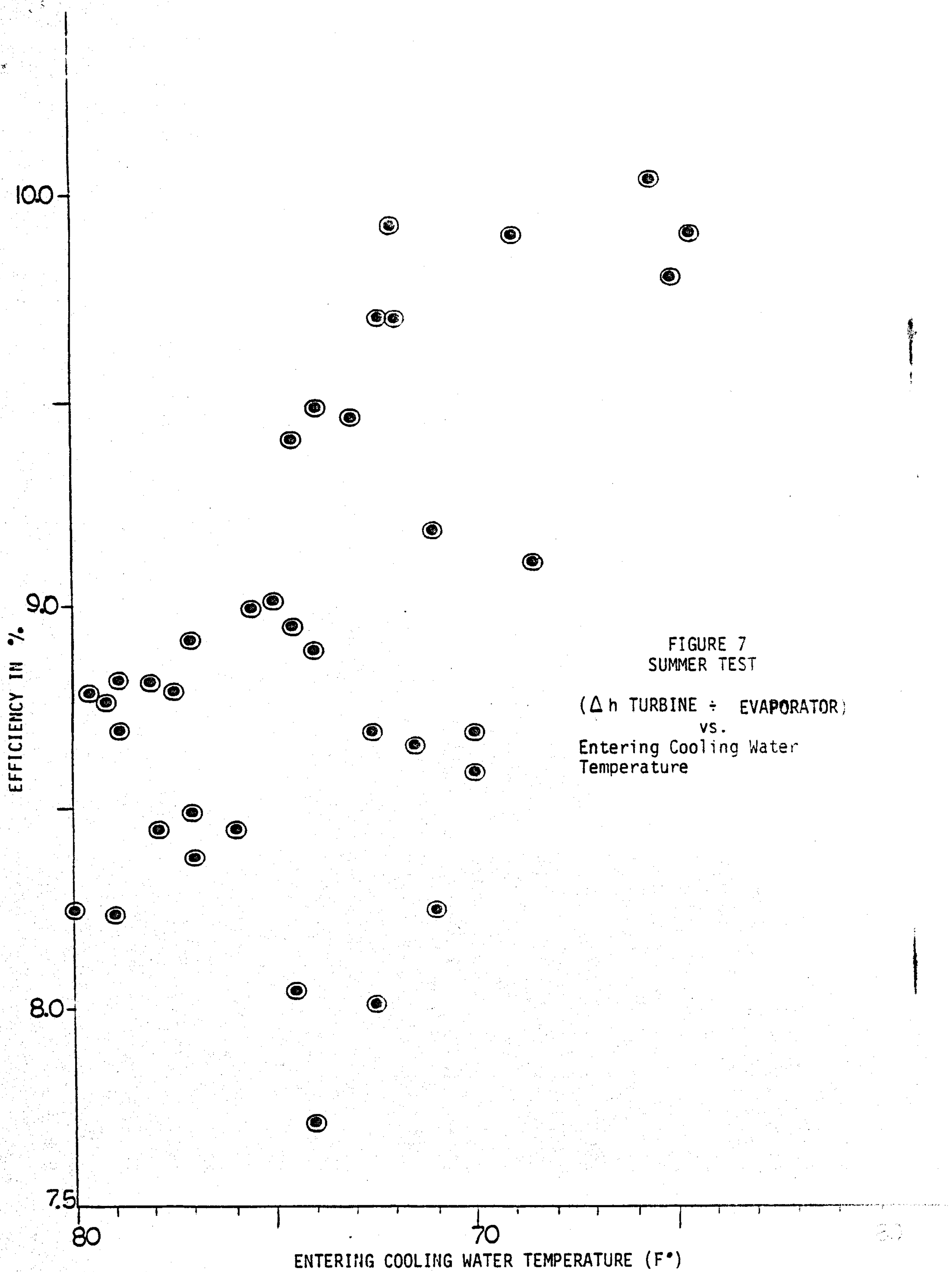


FIGURE 7
SUMMER TEST

(Δ h TURBINE ÷ EVAPORATOR)
vs.
Entering Cooling Water
Temperature

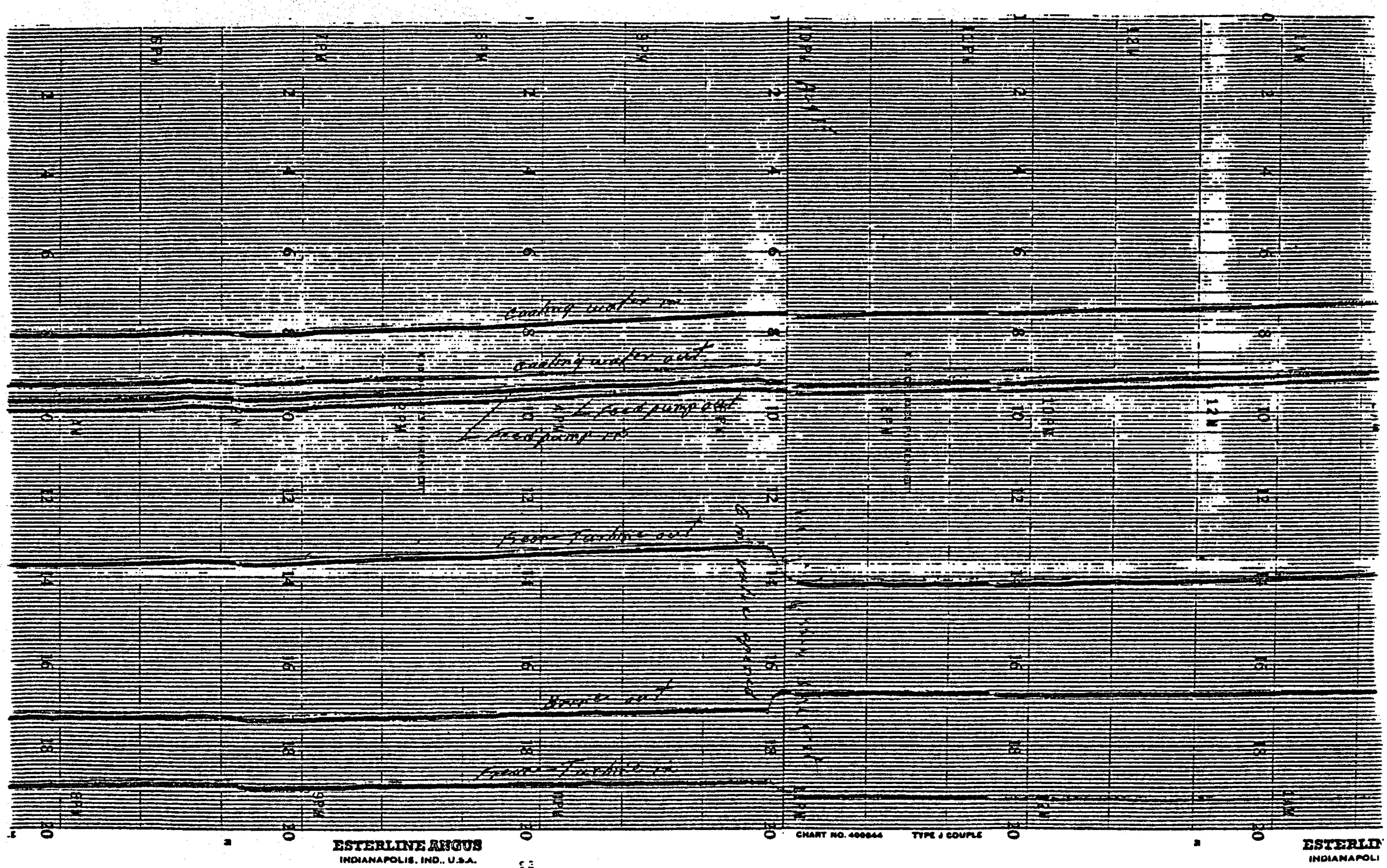

Cooling water in
Cooling water out
Freon turbine out
Brine out
Freon turbine in
ESTERLINE ANGUS
INDIANAPOLIS, IND., U.S.A.
TYPE J COUPLE

Figure 8

TABLE 6

INPUT: DATA FILE								
TIME:	S0800	S0900	S1100	S1200	S1400	S1500	S2100	S2200
DEAD STATE:	CW	CW	CW	CW	CW	CW	CW	CW
T(0)	72	72	71	71.5	79	79	74	75.5
H(0)	40.049	40.049	39.051	39.55	47.039	47.039	42.046	43.544
S(0)	.0783	.0783	.0764	.0774	.0914	.0914	.0821	.0849
GEO-FLUID								
Q(2)	100.19	82.16	82.16	82.16	82.16	110.21	110.21	110.21
VF(2)	.016054	.01639	.01639	.016414	.016434	.016466	.016451	.016431
M(2)	6240.812	5012.813	5012.813	5005.483	4999.392	6693.186	6699.289	6707.443
T(1)	221	221	221	221	221	221	221	221
H(1)	189.24	189.24	189.24	189.24	189.24	189.24	189.24	189.24
S(1)	.3256	.3256	.3256	.3256	.3256	.3256	.3256	.3256
E(1),KW	1942.917	1560.611	1581.499	1571.053	1410.139	1887.894	2031.046	1990.505
T(2)	168	159	159	163.5	167	172.5	170	166.5
H(2)	135.97	126.96	126.96	131.46	134.97	140.48	137.97	134.47
S(2)	.2441	.2297	.2297	.2369	.2425	.2531	.2473	.2417
E(2),KW	852.4862	565.4259	577.8627	632.5520	574.6170	745.7756	914.1244	826.7556
COOLING WATER								
T(7)	72	72	71	71.5	79	79	74	75.5
Q(7)	285.5	285.5	285.5	285.5	285.5	285.5	285.5	285.5
VF(7)	.016082	.016082	.016035	.016035	.01607	.01607	.016058	.016062
M(7)	17752.77	17752.77	17804.80	17804.80	17766.02	17766.02	17779.30	17774.87
H(7)	40.049	40.049	39.051	39.55	47.039	47.039	42.046	43.544
S(7)	.0783	.0783	.0764	.0774	.0914	.0914	.0821	.0849
E(7),KW	0	0	0	0	0	0	0	0
T(8)	83	83.5	84	84	90	91	86.5	88
H(8)	51.031	51.53	52.029	52.029	58.018	59.016	54.525	56.022
S(8)	.09875	.09968	.1006	.1006	.1115	.1134	.1052	.1079
E(8),KW	34.12697	35.54603	42.50216	48.78424	47.39027	39.43437	47.26628	52.83762
R-114								
DEAD STATE:	CW	CW	CW	CW	CW	CW	CW	CW
T(00)	72	72	71	71.5	79	79	74	75.5
H(00)	24.926	24.926	24.685	24.806	26.622	26.622	25.409	25.772
S(00)	.05236	.05236	.05191	.05214	.05552	.05552	.05327	.05395
T(3)	91	89	90	89.5	97	97.5	93	94
Q(3)	52.3	55.43	56.6	49.8	49.78	52.04	53.5	57.7
VF(3)	.011135	.011158	.011172	.0111165	.011269	.011276	.011213	.011227
M(3)	4673.905	4967.736	5066.237	4479.327	4417.428	4615.112	4771.248	5139.396
H(3)	29.828	29.309	29.551	29.449	31.3	31.44	30.326	30.552
S(3)	.061	.0601	.0605	.0603	.0636	.0639	.0619	.0622
E(3),KW	25.73817	23.75350	27.81198	24.68140	25.66969	25.03894	26.52331	28.56091
T(4)	189	182	185	183	184	184	188	191
H(4)	97.38	96.32	97.23	96.35	96.56	97.25	97.17	98.29
S(4)	.1689	.169	.1697	.1676	.1679	.1685	.1685	.171
E(4),KW	862.5646	862.8491	893.9738	804.4948	730.1648	792.5999	861.1143	892.3341
T(5)	130	134	136	128	133	136	131.5	141
H(5)	90.53	91.25	91.58	90.09	90.91	91.4	90.65	92.39
S(5)	.1723	.1735	.1738	.171	.1717	.1721	.1714	.1743
E(5),KW	150.8825	167.4603	196.9779	169.2558	132.4324	160.6326	184.4122	199.7010
T(6)	88	87	88.5	88	94	95	91	92
H(6)	28.825	28.584	28.956	28.832	30.309	30.561	29.571	29.817
S(6)	.05955	.0592	.0599	.0596	.0623	.0628	.061	.0614
E(6),KW	6.271444	1.866931	2.756251	4.998745	2.703863	1.418411	3.080934	5.238843

TABLE 6 cont'd

OUTPUT: SECOND LAW ANALYSIS

TIME:	S0800	S0900	S1100	S1200	S1400	S1500	S2100	S2200
A. EVAPORATOR								
EXERGY DROP IN GEO-FLUID (KW):	1090.43	995.18	1003.64	938.50	835.52	1142.12	1116.92	1163.75
EXERGY RISE IN R-114 (KW):	836.83	839.10	866.16	779.81	704.50	767.56	834.59	863.77
2ND LAW EFFICIENCY:	.77	.84	.86	.83	.84	.67	.75	.74
B. CONDENSER								
EXERGY DROP IN R-114 (KW):	144.61	165.59	194.22	164.26	129.73	159.21	181.33	194.46
EXERGY RISE IN COOLING WATER (KW):	34.13	35.55	42.50	48.78	47.39	39.43	47.27	52.84
2ND LAW EFFICIENCY:	.24	.21	.22	.30	.37	.25	.26	.27
C. FEED PUMP								
EXERGY RISE IN R-114 (KW):	19.47	21.89	25.06	19.68	22.97	23.62	23.44	23.32
2ND LAW EFFICIENCY:	.35	.40	.46	.36	.42	.43	.43	.42
D. TURBINE								
EXERGY DROP (KW):	711.68	695.39	697.00	635.24	597.73	631.97	676.70	692.63
E. UNIT ENERGY DELIVERED (KWH/TON)								
BASED ON TURBINE EXERGY DROP:	3.80	4.62	4.63	4.23	3.99	3.15	3.37	3.44
BASED ON NET POWER TO BUSBAR:	.00	.00	.00	.00	.00	.00	.00	.00
F. MECHANICAL POWER DEVELOPED BY TURBINE:	.00	.00	.00	.00	.00	.00	.00	.00
TURBINE INTERNAL 2ND LAW EFFICIENCY:	.00	.00	.00	.00	.00	.00	.00	.00
TURBINE ABSOLUTE 2ND LAW EFFICIENCY:	.00	.00	.00	.00	.00	.00	.00	.00
G. NET ELECTRICAL POWER DELIVERED TO BUSBAR:	.00	.00	.00	.00	.00	.00	.00	.00
NET PLANT 2ND LAW EFFICIENCY								
BASED ON INLET GEO-FLUID EXERGY:	.00	.00	.00	.00	.00	.00	.00	.00
BASED ON GEO-FLUID EXERGY DROP:	.00	.00	.00	.00	.00	.00	.00	.00
H. THERMAL EFFICIENCY:	.11	.08	.08	.10	.09	.10	.11	.09
I. ACTUAL MODULE EFFICIENCY:								
J. OVERALL PLANT EFFICIENCY:								

Condenser inlet temperature was still being influenced by the previous night's cooling and the exergy drop in freon was higher; however, due to the increase in freon flow, the efficiency dropped slightly and exergy of the cooling water increased slightly.

The overall effect was a reduction in the exergy drop across the turbine and presumably lower electrical output even though more freon was flowing through the turbine.

There were no changes in valve settings between 0900 and 1100 and by comparing temperatures and exergy available at the measuring points, some effects of the mass temperature inertia in the evaporator and condenser can be seen. Exergy drop across the turbine; however, changed very little as the machine reached new equilibrium conditions.

At 1115 hours, the 4" turbine inlet valve was closed and the 1200 data showed a decrease in exergy drop across the turbine of 61.7 kW.

By 1400 hours, turbine exergy drop had decreased to approximately 600 kW due to an increase in cooling water temperature. At 1415, the brine discharge valve was opened, allowing higher flows through the evaporator and resulted in an increase in exergy drop across the turbine of about 6%.

By 2100 exergy drop had increased another 7% due to a decrease in cooling water temperature and at 2132 hours, the 6" turbine inlet valve was opened. The increase in freon flow and turbine exergy drop was surprisingly small.

Although there were slight changes later that night as the machine reached new equilibrium conditions and cooling water continued to cool slightly, the overall effect of opening the 6" valve was relatively small.

Since our primary intent was to measure machine performance, we believed the kWh meter was functioning properly, there were office and living space cooling loads, and considerable activity at the maintenance shop which we wanted to exclude from our data, we did not take readings from SPPC's bi-directional meter until late in the test when we suspected something was wrong. Early in the morning of August 16th, four readings of the bi-directional meter were noted. Between 0600 and 0700, 400.2 kWh had been fed to the grid, 400.2 kWh between 0700 and 0800, and 405 kWh between 0800 and 0900. Calculated exergy drop across the turbine at that time was approximately 685 kW.

The total parasitic load for the Ormat system was 241.6 kW and loads associated with the living, office and maintenance areas probably were on the order of 4-5 kW. This would mean that the calculated exergy drop was 4.8% high.

$$405 + 241.6 + 5 = 651.8 \text{ kW}$$

$$\frac{685 - 651.8}{685} = 4.8\% \text{ high}$$

This is in the error range for the flow rates determined during the flow meter calibration.

If the brine flow meter error was 5% high, then the following conditions existed during the last few hours of the summer test.

Brine inlet temeprature = 221°F

Brine flow = 833 gpm = 402,839 lb/hr

Cooling water inlet temperature = 64.5°F

Cooling water flow = 2220 gpm

Gross power = 651.8

Parasitic loads = 247.6

Net resource utilization efficiency:

405 kW ÷ 402,839 lb/hr = 1.005 Whr/lb

Net heat rate:

402,839 lb/hr x 55 Btu/lb ÷ 405 kW = 54,706 Btu/kWh

Net thermal efficiency:

3413 Btu/kWh ÷ 54,706 Btu/kWh = 6.2%

Fall Test

The fall test was scheduled for October 15, 1985. Four pressure gauges that had experienced vibration damage were replaced with calibrated gauges and flow instrumentation installed during the morning. The test started at 1 pm on October 15 and ended at 1 pm October 16. Representatives of the same utilities and OIT were on hand to take and record data, as were TAD's and Ormat personnel.

The test appeared to be free of the problems experienced during the summer test. TAD's had installed a meter which provided a paper tape record of electrical output and power factor which agreed within 1.2% to 1.4% with the kW readings taken by counting meter wheel turns and recording times from the stop watch. The new kWh meter had recently been calibrated in SPPC's meter shop. Electrical output readings from the tape were used in calculations since it was assumed they were more accurate than the counting turns method.

A new data sheet for recording spray pond information had been developed by SPPC. The sheet included a more complete temperature profile of the pond (see Appendix F). In addition, a second "thief" cup was installed in order to take spray temperature between nozzles in the interference area. During the summer test temperatures had been taken only at the end of the spray and from a single nozzle. Pond readings were taken every two hours.

A program for Texas Instrument hand held calculator TI 59 had been developed by the OIT Geo-Heat Center to test the accuracy of the input data. The program calculates an energy balance for the system using enthalpies internally calculated from temperature and pressure data.

The only problem noted during the test was an unexplained decrease in well flow readings for a period of 4 hours (0400 through 0700), suggesting there may have been a problem with the sensors or instrument electronics. Subsequent flow meter calibration tests run at the University of California, Davis, water resources lab indicate that the flow meters read 2.5 - 10% high in the range of flows in the Ormat unit. The reason for the temporary decrease in readings has not been explained but energy balance calculations indicate they were in error. Flow rates were adjusted down 4% for all subsequent calculations.

Appendix D contains raw data taken at the site.

During the fall (second) test, the machine appeared to run flawlessly. Only one operating change was made when the brine discharge valve was opened from nearly open to full open at 1430 hours. This reduced the brine inlet pressure from 25.5 psi to 17 psi and brine outlet pressure from 10 psi to 2 psi. Indicated brine flow increased slightly but a brine outlet temperature change was not noted until 1600 hours when it had increased 1.5°F and remained essentially constant for the remainder of the test. Preliminary heat balances calculated at the site indicated no real problems with data but indicated a higher machine efficiency than during the summer test. This was to be expected since the cooling water was nearly 20°F cooler than during the summer test.

Graphs of measured output and efficiency vs entering cooling water temperature (Figs. 9 & 10) were prepared. Although there was some scatter in the efficiency data, it appeared to be less than 1% and the measured output vs cooling water temperature was reasonably close to a straight line. Note that a 5°F decrease in entering cooling water temperature results in a 35 kW increase in output. No further analysis of the data were done until after the last test.

Table 7 shows a computer printout of the available work analysis for selected data points of the fall test. This analysis indicates a real problem somewhere in the data - probably in the measured freon flow rates (and indicates possible errors in all flow rates). Note that although measured electrical output to the busbar is some 50 to 76 kW higher than summer test values (assuming output was constant during the three one hour intervals busbar output was measured during the summer test) exergy drop across the turbine is similar to summer values and turbine efficiencies are all greater than 100%.

Assuming that measured brine flow was 5% high and cooling water flow was correct (as was done for the summer test), the following conditions existed.

Brine inlet temperature = 221°F

Brine outlet temperature = 161°F

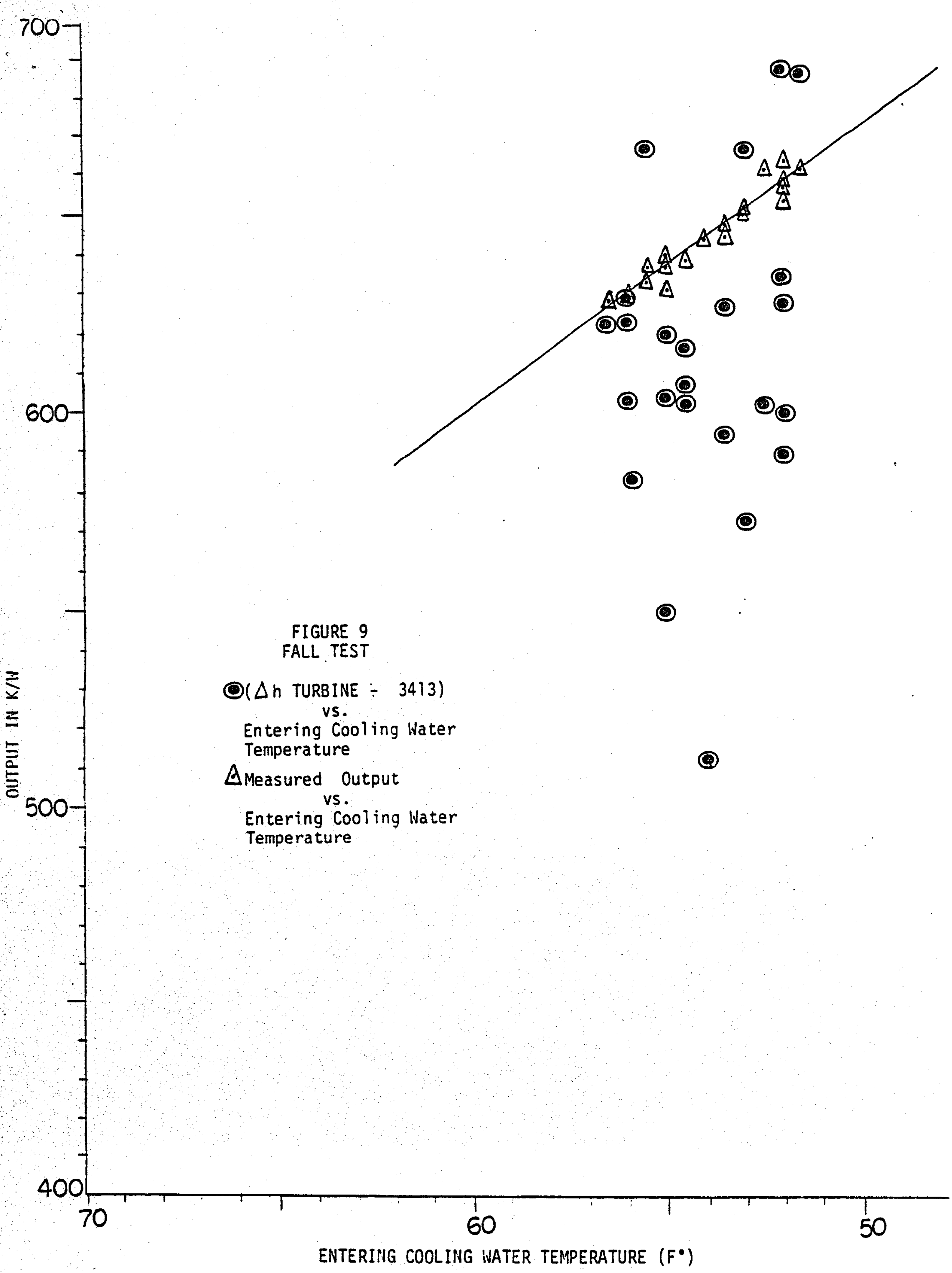


FIGURE 9
FALL TEST

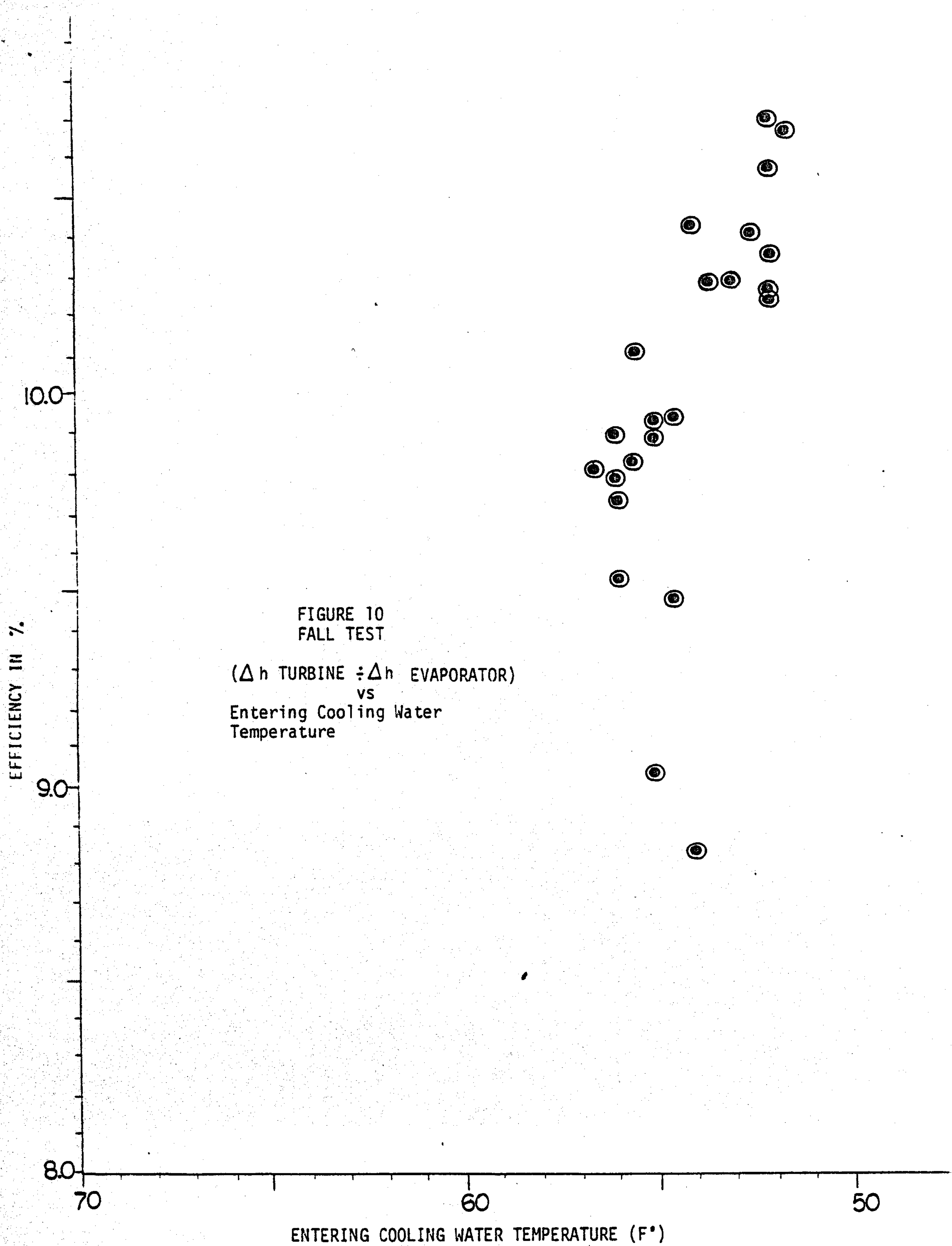


FIGURE 10
FALL TEST
(Δh TURBINE ÷ Δh EVAPORATOR)
vs
Entering Cooling Water
Temperature
EFFICIENCY IN %
10.0
9.0
8.0
70
60
50
ENTERING COOLING WATER TEMPERATURE (F°)

TABLE 7

INPUT: DATA FILE				
TIME:	F1400	F1500	F2100	F0800
DEAD STATE:	CW	CW	CW	CW
T(0)	56	56	58.5	55
H(0)	24.059	24.059	26.56	23.059
S(0)	.0478	.0478	.0526	.0459
GEO-FLUID				
Q(2)	100.19	102.6	102.6	102.6
VF(2)	.016395	.016395	.016403	.016403
M(2)	6111.009	6258.005	6254.953	6254.953
T(1)	221	220	220	220
H(1)	189.24	188.23	188.23	188.23
S(1)	.3256	.3241	.3241	.3241
E(1),KW	2355.745	2386.393	2307.757	2418.045
T(2)	160	160	161.5	161.5
H(2)	127.96	127.96	129.46	129.46
S(2)	.2313	.2313	.2337	.2337
E(2),KW	996.4872	1020.457	996.1919	1071.688
COOLING WATER				
T(7)	56	56	58.5	55
Q(7)	269.77	269.77	269.77	269.77
VF(7)	.016028	.016028	.016032	.016027
M(7)	16831.17	16831.17	16826.97	16832.22
H(7)	24.059	24.059	26.56	23.059
S(7)	.0478	.0478	.0526	.0459
E(7),KW	0	0	0	0
T(8)	71.5	72	74	71
H(8)	39.55	40.049	42.046	39.051
S(8)	.07735	.0783	.0821	.0764
E(8),KW	74.84632	77.54293	59.15919	87.16486
R-114				
DEAD STATE:	CW	CW	CW	CW
T(00)	56	56	58.5	55
H(00)	21.108	21.108	21.699	20.872
S(00)	.0451	.0451	.04624	.04465
T(3)	80.5	80.5	82.5	79.5
Q(3)	52	54.3	53.2	53.2
VF(3)	.011045	.011045	.011071	.011032
M(3)	4708.013	4916.252	4805.347	4822.335
H(3)	27.24	27.24	27.72	26.991
S(3)	.0563	.0563	.0572	.0558
E(3),KW	29.95922	31.28434	29.32292	32.74687
T(4)	193.5	192.5	192.5	193.5
H(4)	99.16	98.88	98.88	99.08
S(4)	.173	.1724	.1724	.1727
E(4),KW	1001.298	1048.127	997.5731	1043.135
T(5)	135.5	136	137	135.5
H(5)	91.38	91.58	91.8	91.34
S(5)	.1726	.1738	.1745	.1723
E(5),KW	374.4435	354.8092	307.5435	404.4164
T(6)	79	79.5	81	79
H(6)	26.639	26.76	27.124	26.635
S(6)	.0556	.0558	.0565	.0556
E(6),KW	9.639443	11.60992	9.172267	10.79745
N OUTPUT: GE	695.5	697.6	695	718.8
BUSBAR:	453.5	455.6	453	476.8
MOD OUTPUT:	640.5	642.6	640	663.8

TABLE 7 cont'd

OUTPUT: SECOND LAW ANALYSIS

TIME:	F1400	F1500	F2100	F0800
A. EVAPORATOR				
EXERGY DROP IN GEO-FLUID (KW):	1359.26	1365.94	1311.57	1346.36
EXERGY RISE IN R-114 (KW):	971.34	1016.84	968.25	1010.39
2ND LAW EFFICIENCY:	.71	.74	.74	.75
B. CONDENSER				
EXERGY DROP IN R-114 (KW):	364.80	343.20	298.37	393.62
EXERGY RISE IN COOLING WATER (KW):	74.85	77.54	59.16	87.16
2ND LAW EFFICIENCY:	.21	.23	.20	.22
C. FEED PUMP				
EXERGY RISE IN R-114 (KW):	20.32	19.67	20.15	21.95
2ND LAW EFFICIENCY:	.37	.36	.37	.40
D. TURBINE				
EXERGY DROP (KW):	626.85	693.32	690.03	638.72
E. UNIT ENERGY DELIVERED (KWH/TON)				
BASED ON TURBINE EXERGY DROP:	3.42	3.69	3.68	3.40
BASED ON NET POWER TO BUSBAR:	2.47	2.43	2.41	2.54
F. MECHANICAL POWER DEVELOPED BY TURBINE:	695.50	697.60	695.00	718.80
TURBINE INTERNAL 2ND LAW EFFICIENCY:	1.11	1.01	1.01	1.13
TURBINE ABSOLUTE 2ND LAW EFFICIENCY:	.69	.67	.70	.69
G. NET ELECTRICAL POWER DELIVERED TO BUSBAR:	453.50	455.60	453.00	476.30
NET PLANT 2ND LAW EFFICIENCY				
BASED ON INLET GEO-FLUID EXERGY:	.19	.19	.20	.20
BASED ON GEO-FLUID EXERGY DROP:	.33	.33	.35	.35
H. THERMAL EFFICIENCY:	.12	.11	.11	.13
I. ACTUAL MODULE EFFICIENCY:	.10	.10	.10	.10
J. OVERALL PLANT EFFICIENCY:	.07	.07	.07	.07

Brine flow = 774 to 813 gpm = 374,306 to 393,167 lb/hr

Cooling water inlet temperature = 55 to 58°F

Cooling water flow = 2150 gpm

Gross power = 821 to 852 kW

Parasitic loads = 241.6 kW

Net resource utilization efficiency = 1.55 Whr/lb

Net heat rate = 38,761 to 38,647 Btu/kWh

Net thermal efficiency = 8.8 to 9.4%

Winter Test

The winter test was finally run March 6 and 7, 1986 after several aborted schedules. On December 19, all personnel were at the site and instrumentation had been installed when a short in the primary power cable between the main switch gear and the Ormat control cabinet shut the unit down for repairs and the test was canceled. As noted earlier, another scheduled test was canceled due to a failure in the well pump power cable seal. Although certainly not of benefit to TAD's, this did provide the opportunity to install a new bubbler tube in the well allowing pumping water level to be measured during the third test.

Although weather conditions for the "winter" test were actually warmer than the "fall" test, the test was run without problems. All dial thermometers were checked in a hot oil bath and thermocouple calibration was checked. Pressure gauges were checked with a dead weight tester and reinstalled on the unit the afternoon of March 5. Although the electrical output recorder was not available, a TIF meter was connnected at the control cabinet as a check on the counting turns method of obtaining output. In addition, readings were taken from SPPC's bi-directional meter used as the basis for power payments to TAD's. This meter reads net power into and out of the entire site including all associated uses such as maintenance shop, etc., but during this test these uses were small compared to the generator output.

Appendix E contains raw data taken at the site during the test.

As in the second test, the system operated very well during the test. There were no valve changes that could have affected brine flow, and temperatures and pressures remained surprisingly constant throughout the test. Cooling water inlet temperature, which is a major factor affecting electrical output ranged from a low of 59.5°F to a high of 61°F. Measured electrical output varied from a high of 578.4 kW to a low of 552.7 kW with electrical output varying inversely with cooling water inlet temperature.

One important factor noted during the test was that the well bubbler tube pressure did not vary from 32 psi during the test, indicating a constant pumping level of 205.5 feet with the tube setting of 283 feet below the wellhead. Although the evaporator brine inlet pressure gauge was inoperative, evaporator brine outlet pressure and wellhead pressure remained constant at 4 psi and 23 psi respectively. During the test, brine flow meter readings varied from 5.5 feet/second to 5.95 feet/second, a variation of approximately 8%. Corresponding flow rates are 5.5 feet/second = 877 gpm, and 5.95 feet/second = 950 gpm. There appears to be no reasonable explanation for such a large variation in flow rates with constant pumping level and pressure except flow meter error.

Also during the test, indicated freon flow rates varied from 6.6 feet/second to 7.4 feet/second while freon temperatures and pressures remained relatively constant. Second law analysis gives an inverse relationship between exergy drop across the turbine and generator output during the high freon flow at 1430 hours and one of the low freon flows at 0730 hours the second day. At 1430 hours, indicated freon flow was 7.4 feet/second, calculated exergy drop 842 kW and measured electrical output

568.8 kW. At 0730 hours, indicated freon flow was 6.6 feet/second, calculated exergy drop 828.7 kW and measured electrical output was 575.7 kW. Temperatures and pressures in the freon loop were identical within probable instrument error at both times. There is no explanation except that the flow meter readings were in error.

Table 8 shows the second law analysis calculated from data taken at 1430 hours and 0730 hours.

Again, assuming a 5% high error in brine flow, and cooling water flow was correct, the following conditions existed.

Brine inlet temperature = 221°F

Brine outlet temperature = 163°F

Brine flow = 813 gpm = 393,167 lb/hr

Cooling water inlet temperature = 60°F

Cooling water flow = 2100 gpm

Gross power = 739.3 to 765 kW

Parasitic loads = 241.6

Net resource utilization efficiency = 1.27 to 1.33 Whr/lb

Net heat rate = 43,568 to 45,818 Btu/kWh

Net thermal efficiency = 7.5 to 7.8%

TABLE 8

INPUT: DATA FILE		
TIME:	W1430	W0730
DEAD STATE:	CW	CW
T(0)	61	59.5
H(0)	29.06	27.56
S(0)	.0574	.0545
GEO-FLUID		
Q(2)	118.2	115.4
VF(2)	.016401	.016406
M(2)	7206.878	7034.012
T(1)	221	221
H(1)	189.24	189.24
S(1)	.3256	.3256
E(1),KW	2601.886	2588.533
T(2)	163	162
H(2)	130.96	129.96
S(2)	.2361	.2345
E(2),KW	1122.062	1106.664
COOLING WATER		
T(7)	61	59.5
Q(7)	257.1	257.1
VF(7)	.016035	.016033
M(7)	16033.68	16035.68
H(7)	29.06	27.56
S(7)	.0574	.0545
E(7),KW	0	0
T(8)	79	76
H(8)	47.039	44.043
S(8)	.0914	.0858
E(8),KW	77.85869	65.67846
R-114		
DEAD STATE:	CW	CW
T(00)	61	59.5
H(00)	22.292	21.937
S(00)	.04738	.0467
T(3)	87.5	86
Q(3)	80.8	76.7
VF(3)	.011125	.011118
M(3)	7262.921	6898.723
H(3)	28.947	28.58
S(3)	.0594	.0587
E(3),KW	51.40955	50.85280
T(4)	186.5	186
H(4)	97.68	97.58
S(4)	.1706	.1704
E(4),KW	1434.004	1385.215
T(5)	137	136
H(5)	91.45	91.32
S(5)	.1713	.1715
E(5),KW	592.0077	556.7439
T(6)	86	84.5
H(6)	28.352	27.983
S(6)	.0587	.0581
E(6),KW	21.19723	15.45853
N OUTPUT: GE	623.8	630.7
BUSBAR:	381.8	388.7
MOD OUTPUT:	568.8	575.7

TABLE 8 cont'd

OUTPUT: SECOND LAW ANALYSIS

	TIME: W1430	W0730
A. EVAPORATOR		
EXERGY DROP IN GEO-FLUID (KW):	1479.82	1481.87
EXERGY RISE IN R-114 (KW):	1382.59	1334.36
2ND LAW EFFICIENCY:	.93	.90
B. CONDENSER		
EXERGY DROP IN R-114 (KW):	570.81	541.29
EXERGY RISE IN COOLING WATER (KW):	77.86	65.68
2ND LAW EFFICIENCY:	.14	.12
C. FEED PUMP		
EXERGY RISE IN R-114 (KW):	30.21	35.39
2ND LAW EFFICIENCY:	.55	.64
D. TURBINE		
EXERGY DROP (KW):	842.00	828.47
E. UNIT ENERGY DELIVERED (KWH/TON)		
BASED ON TURBINE EXERGY DROP:	3.89	3.93
BASED ON NET POWER TO BUSBAR:	1.77	1.84
F. MECHANICAL POWER DEVELOPED BY TURBINE:	623.80	630.70
TURBINE INTERNAL 2ND LAW EFFICIENCY:	.74	.76
TURBINE ABSOLUTE 2ND LAW EFFICIENCY:	.44	.46
G. NET ELECTRICAL POWER DELIVERED TO BUSBAR:	381.80	388.70
NET PLANT 2ND LAW EFFICIENCY		
BASED ON INLET GEO-FLUID EXERGY:	.15	.15
BASED ON GEO-FLUID EXERGY DROP:	.26	.26
H. THERMAL EFFICIENCY:	.10	.10
I. ACTUAL MODULE EFFICIENCY:	.08	.08
J. OVERALL PLANT EFFICIENCY:	.05	.05

Performance Tests Summary

The summer test, which would have been the best one to perform detailed thermodynamic analysis on because of changing flow and temperature conditions, was unfortunately plagued with problems. Not only was the kW output meter found to be giving false readings, geothermal water, freon and cooling water data are probably also in error. Geothermal water flow rates, although they remained stable between discharge valve changes, are now suspect because of obvious errors in other flow measurements. Freon flows, although appearing to be accurate, even in the limited thermodynamic analysis, cannot be closely checked because generator output and, therefore, turbine exergy was found to be in error. Cooling water flow changes were assumed to be caused by intermittent partial pump cavitation during the test. Although this is still a possible cause of error, the flow meter, therefore the flow rate data still are suspect.

Possible problems with the flow meters were first noted late in the second test when four consecutive abnormally low flow rates were noted. Subsequent close scrutiny of flow rates indicate that early in the test small changes in discharge valve settings resulted in changes in brine pressures but did not result in corresponding changes in brine flows as they should have. Thermodynamic analysis of the Ormat unit operation during the second test substantiated problems with the freon flow meter since calculated turbine thermal efficiencies were greater than unity and exergy drops did not correspond to changes in generator output.

Attempts to calibrate the flow meters resulted in mixed data. At this time, it is not known if this was due to the flow meters themselves, operation of the calibration unit or both.

Probable flow meter errors were substantially confirmed during the third test by well pumping data and thermodynamic analysis.

During all the tests, the Ormat unit appeared to operate satisfactorily and despite the lack of rigorous thermodynamic analysis due to the flow meter problems, operation appeared to be as expected.

Spray Pond Performance

Description of the Spray Ponds

The heat rejection system for the Ormat unit at TAD's consists of two above ground diked unlined spray ponds, each of which is about 125' x 400'. The ponds are connected in series with a 50 hp pump circulating the water from second pond through the unit and then back through the sprays that are over the first pond. Two 10 hp pumps take water from the first pond and circulate it through nozzles over the second pond. Equalizing lines between these ponds assist in maintaining equal water levels in the ponds and proper suction pressures to the main circulating pump. The main circulating pump's suction is valved so that it can be pumped from either or both ponds.

Spray Pond Performance

Spray pond performance averaged about 63% based on the 25 observations taken over two different 24 hour periods. The average temperatures recorded were:

Dry bulb temperature	52°F
Wet bulb temperature	45°F
Temperature of water to sprays over the first pond	75°F
Temperature of the water from the ponds	56°F

Temperature of the water from the edge of the spray pattern — 56°F

Approach temperature (spray water temperature - wet bulb temperature) 56-45 = — 11°F

Performance efficiency =

$$\frac{(T\ \text{water in} - T\ \text{wet bulb}) - (T\ \text{water out} - T\ \text{wet bulb})}{T\ \text{water in} - T\ \text{wet bulb}}$$

Good spray pond performance would show an approach temperature of 4-6°F and excellent performance would be in the range of 2-4°F. The approach temperature of the spray water to the wet bulb temperature improved dramatically when the wind blew during periods of low relative humidity. On the other hand, the night time performance of the spray pond was generally poor because the ambient humidity of the air near the ponds was high and there was little air movement. The lower ambient temperatures, however, tended to compensate for this poor performance. The combination of wind and temperature experienced over the test period tended to keep the pond outlet temperature within a range of 7°F (53-60°F) while the ambient air dry bulb temperature ranged 40°F (70-30°F).

The overall efficiency of the original cooling system was probably increased 20% by adding the second pond and respraying the water to obtain additional cooling even though the cooling efficiency of this second pond is probably in the range of 35% during most periods of operation.

8. Reliability and Operational Data

Monthly availability , power sales, capacity factor and average output per hour on line for the months of August 1985 through March 1986 are shown in Table 9. Capacity factor was calculated on the basis of the nominal 600 kW rating of the unit and 186.6 kW of the parasitic load. The parasitic load includes the well pump, cooling water pump and transfer pumps. Data on each of the parasitic loads are shown in Appendix G. The feed pump, lube oil pump and air compressor are considered a part of the unit.

Capacity factor = Power sales kWh per month divided by (nominal rating - parasitic loads) x total hours that month

i.e. November power factor = 304,000 divided by (600 - 186.6) x 30 x 24 = 1.02

Because the nominal rating is based on a cooling water inlet temperature of 65°F and the spray ponds are capable of providing cooler water during cold weather, the capacity factor can, and did, exceed unity during some months even though availability was less than 100%.

Ormat unit availability is based on the number of hours the unit was operated and the number of hours the system outside the unit (cooling water, geothermal water and electric grid) were available.

Unit operating hours divided by support system available hours x 100 = % unit available

Table 9

Production Data August-March

onth	Possible Hours	System Avail. Hour	System % Avail.	Ormat Unit % Avail.	Production MWh	Capacity Factor	Avg. Site Output/Hr. On Line	Avg. Unit Output/Hr. On Line	Avg. Gen. Output/Hr. On Line
ug	744	534.2	71.8	90.6	142	.46	265.8	452.4	507.4
ept	720	657.4	71.3	94.9	252	.85	383.3	569.9	624.9
ct	744	622.0	83.6	97.5	257	.84	413.2	599.8	654.8
ov	720	671.0	93.2	96.1	304	1.02	453.1	639.7	694.7
ec	744	644.3	86.6	86.5	311	1.01	482.7	669.3	724.3
an	744	702.3	94.4	98.8	314	1.02	447.1	638.7	688.7
eb	672	428.7	63.8	99.9	245	.88	571.5	758.1	813.1
lar	744	739.5	99.4	99.9	292	.94	394.9	581.5	636.5

Although availability data are not shown prior to August, power sales for the 12 month period of April 1985 through March 1986 amounted to 2809 Mw hours. Capacity factor for that one year period was 77.5%.

By far the largest number of faults have been due to electric grid fluctuations and outages. If the grid was available, the unit was quickly restarted, usually within 15 minutes.

For the Ormat unit, shut down for scheduled maintenance operations has generally been less than two hours. Operations requiring shut down are items such as changing lube oil filters, taking samples of the freon for analysis, replacing feed pump packings, and electrical and controls checks.

Other regular maintenance procedures, such as greasing feed pump and motor bearings and adding lube oil, do not require shut down.

Comments by TAD's indicate they feel the unit is easy to operate and maintain. If a failure occurs, the unit automatically shuts down and indicator lights show what the cause for shut down was. Once the problem is located and corrected, restart is accomplished by pushing one start button.

All rotating equipment, pumps, motors, turbine and generator are readily accessible in case of failure. For instance, the daily log shows that a shut down of four hours was required to replace the feed pump motor.

The logs indicate the generator has been repaired or replaced three times since initial installation. Apparently the problems have been due to overheating. In December of 1985, the end turns were banded to prevent expansion due to heating and the problem had not recurred as of May 1986. The logs are somewhat incomplete but apparently the generator can be changed out in one day.

The only other recurring problem has been overheating of circuit breakers in the control cabinet. This was probably partly due to the fact that the control cabinet was designed for operation in an air conditioned room rather than in the Nevada sun. This could also have been contributed to by faulty feeder wiring installation between the control cabinet and the main switch gear cabinet which caused a short to ground in January. Apparently, each of three conduits carried a single phase rather than one wire of each of the three phases which resulted in overheating and melting of insulation. Control cabinet overheating could be reduced by constructing a simple open sided structure over the control cabinet to prevent direct exposure to the sun.

9. Comparison of Actual and Computer Predicted Performance

As a part of the OIT Geo-Heat Center's contract with ODOE, the Center was to compare, to the extent possible, actual performance with performance predicted by a computer program developed by OIT in 1983. A direct comparison is not possible since the program was written for a situation where an injection well and cooling towers are utilized rather than the situation at TAD's where surface discharge and cooling ponds are used. The computer programs predicted net saleable power will be somewhat different since the parasitic loads for the two situations are different.

Actually, the difference between computer predicted performance and performance at TAD's was rather close. Using the resource characteristics at TAD's (800 gpm, 221°F, 205' pumping level) and assuming an average wet bulb temperature of 43°F, which were the average conditions during the March test, the program predicts a net saleable power of 2,100 MWh in seven months. Actual power sales to SPPC for the seven month period September 1985 through March 1986 were 1,975 MWh. The program predicted sales 6% higher than actual.

Detailed weather data for the Wabuska area are not available; however, the average wet bulb at Stead Air Force Base near Reno and Tonopah MAP is close to 43° and this was used in the prediction. Changing the program input wet bulb temperature to 44°F results in a seven month net saleable power of 2065 MWh which is only 4% higher than the actual sales September through

March. In order to closely predict sales, wet bulb temperatures at the site would need to be known.

10. Observations and Conclusions

Performance

Only general conclusions can be reached about the performance of the Ormat unit at TAD's. It had been planned to provide a detailed thermodynamic analysis of unit operation under three operating conditions summer, fall and winter. Since it is almost certain the flow meters gave erroneous data, The analysis was not done as the results would have also been erroneous. The analyses giving turbine efficiencies greater than one are a good example of the results of bad data.

Raw data indicates that the geothermal water flow rate varied from approximately 650 gpm, when most of the discharge flow was being used for cooling water make up, to 870 gpm when all the water is being discharged to the aquaculture facility. During one of the flow meter calibration runs, the flow meter used on the geothermal water indicated flows .78 ft/second or 23.8% high. The error analysis indicated that errors in flow measurement are the most critical and an error of that magnitude would result in a calculated turbine exergy drop 17.9% higher than actual.

Based on the pump test performed by G.D.A. and Associates, bubbler pressures during our third test, the pump performance curves and the flow meter calibration runs, a best guess is that the maximum geothermal flow was 800 to 825 gpm. At that flow rate, specific output during the third (winter) test was 1.47 watt hours per pound when cooling water temperature was 59.9°F. The Ormat unit net output was 575.7 kW and thermal efficiency approximately 8.6% under those conditions. Net saleable power was 390 kW. There was good agreement on net saleable power as measured by SPPC's bi-directional meter and measured Ormat unit output minus measured parasitic loads.

Turbine power, therefore generator output, is limited by cooling pond capacity. During hot weather operation, only the 8" turbine inlet valve is open. Although on a cool summer night the 6" valve can be opened, the power output increase appears to be relatively small. Since there is more freon available to extract heat, the brine outlet temperature is reduced, but since the condenser now must remove more heat, its outlet water temperature is raised and turbine inlet and outlet temperature and pressure increase. During the fall test, a decrease in cooling water temperature of 5°F resulted in an increase of 35 kW output.

Cooling pond deficiency was noted early in the summer, before testing was begun, and the second pond was constructed. This probably increased cooling efficiency by 20%, although we had no data prior to testing.

Spray pond performance averaged about 63% during the tests. The approach temperature averaged 11°F, while good spray pond performance wuld be 4-6°F and excellent would be 2-4°F. Approach temperatures improved when the wind blew, but were generally poor at night because of little air movement, resulting in high relative humidity near the ponds. This was compensated for by lower ambient temperatures.

Computer predicted performance is sensitive to wet bulb temperature assumptions. A change of wet bulb temperature of 1°F results in a 2% change in predicted output. Wet bulb temperature at a proposed site needs to be accurately known in order to accurately predict performance.

Reliability, Availability and Maintenance

Examination of the operating logs indicated that before our testing started, the unit experienced difficulties primarily due to overheating problems in the controls and generator. Some of these problems were in the unit itself and some were outside the unit and due to faulty installation. Control cabinet overheating undoubtedly will be helped by the recent rewiring between the cabinet and main switch gear (an installation problem) but could probably be further improved by providing protection from exposure.

By far the largest number of outages were due to electric grid fluctuations and the unit was restarted quickly if the grid was available. Availability of the unit itself was good during the time our testing was in progress, averaging 95.5% for the eight month period.

The operator, TAD's, stated that regular scheduled maintenance is simple and requires only a few hours a month. Based on log book entries it appears that major rotating components can be replaced quickly in case of failure - assuming replacements are available. The remoteness of the site has caused some delays in that respect. There have been no problems with non-rotating components (the evaporator, condenser and piping) due to scaling or corrosion. This, of course, is site specific and the geothermal water at Wabuska is relatively benign.

During colder weather, when the cooling pond has the most capacity, Ormat unit capacity factor exceeds unity even though availability might be less than 100%. For the months of November, December and January, capacity factor was 1.02 while availability was 93.4%.

A P P E N D I C I E S

APPENDIX A

Instrumentation Data

Instrument Data
(EPRI Project RP1195-16, Ormat at Wabuska)

No.	Parameter Name	Unit	Range	Accuracy	Instrument Description
Q_1	Brine Flow	ft/sec	10	2%	Polysonic-accoustic doppler
Q_2	R-114 Flow	ft/sec	10	2%	Polysonic-accoustic doppler
Q_3	Cool. Water Flow	ft/sec	10	2%	Polysonic-accoustic doppler
E_2	Gross Output Power	kWe	any	0.1%	Cycle counts on kWh meter
	Gross Electricity	kWh	10 MWh	1 kWh	kWh meter owned by Ormat
	Net Electricity	kWh	10 MWh	1 kWh	kWh meter owned by SPPC
E_1	Power to Well Pump	kWe	any	3%	Clip on meter owned by SPPC
E_3	Power to Feed Pump	kWe	any	3%	Clip on meter owned by SPPC
E_4	Power to CW Pump	kWe	any	3%	Clip on meter owned by SPPC
E_5	Power to Trans. Pump	kWe	any	3%	Clip on meter owned by SPPC
E_6	Power to Trans. Pump	kWe	any	3%	Clip on meter owned by SPPC
T_0	Well Pump Temp. Out	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{1*}	Brine Temp. In Evap.	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{2*}	Brine Temp. Out Evap.	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{3*}	R-114 Temp. into Evap.	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{4*}	R-114 Temp. into Turb.	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{6*}	R-114 Temp. Turb. Out	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{7*}	R-114 Cond. Out	°F	250	1.5°F	5" dia. bimetallic stem thermometer
T_{8*}	Cool. Water into Cond.	°F	120	1.0°F	5" dia. bimetallic stem thermometer
T_9	Cool. Water out Cond.	°F	125	1.0°F	5" dia. bimetallic stem thermometer
P_0	Well Pump Press. Out	psig	200	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_1	Brine Pressure In Evap.	psig	100	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_2	Brine Pressure Out Evap.	psig	100	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_3	R-114 Press. into Evap.	psig	200	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_4	R-114 Press. into Turb.	psig	200	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_5	R-114 Press. Nozzle Block	psig	250	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_6	R-114 Press. Turb. Ex. Out	psig	125	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_7	R-114 Press. Cond. Out	psig	125	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_8	Cool. Water Press. In Cond.	psig	100	1%	4½" dia. ANSI Grade A bourdon tube gauge
P_9	Cool. Water Press. Out Cond.	psig	100	1%	4½" dia. ANSI Grade A bourdon tube gauge
T_{12}	CW Temp. in Spray	°F	120	1.0°F	12" mercury in glass thermometer
T_{13}	CW Temp. in 1st Pond	°F	120	1.0°F	12" mercury in glass thermometer
T_{14}	CW Temp. in 2nd Pond	°F	120	1.0°F	12" mercury in glass thermometer
T_{15}	Ambient Dry Bulb	°F	-20-130	1.5°F	12" mercury in glass thermometer
T_{16}	Ambient Wet Bulb Temp.	°F	0-110	1.0°F	12" mercury in glass thermometer

*Also measured on an eight point recorder. Temperature sensors were J type iron constantan thermocouples mounted in the thermometer wells used for the dial thermometers.

APPENDIX B

Example Calculation of Available Work (Exergy)

EXAMPLE CALCULATION OF AVAILABLE WORK (EXERGY)

In a geothermal power plant the geothermal fluid does not experience a cycle but rather a series of processes from an initial state to a final state. This is also true where an internal cycle is part of the internal energy process as in the case of binary plants.

A simplified representation of a binary plant operating in a steady-state manner and as described above is shown in Figure 11.

The basic idea of a Second Law analysis is to calculate the available work of the fluids at important state points, and to examine each major component to determine the change in available work. The available work characterizes a fictitious reversible operation to a prescribed dead state of pressure P_o and temperature T_o. In this example cooling water temperature and pressure was used as the dead state.

The First Law of thermodynamics for the system can be written as:

$$Q - W = m(h_i - h_o)$$

Where:

Q = heat in

W = work out

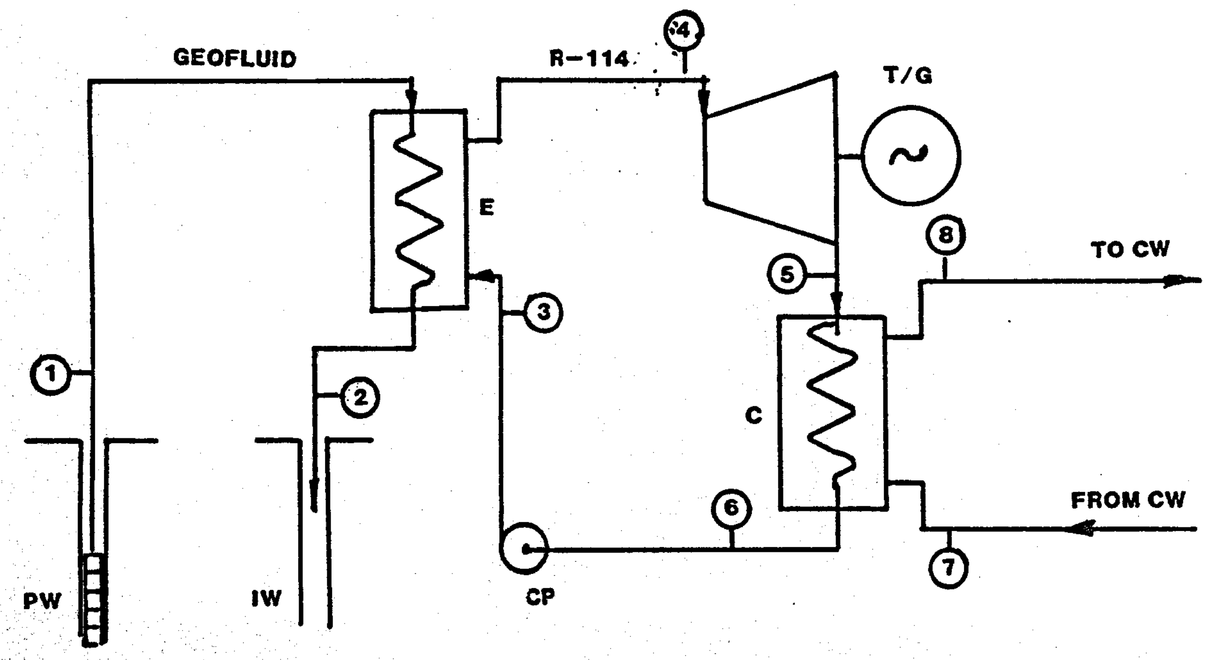


Figure 11

Simplified Schematic of Binary Plant

PW, IW = production, injection wells; E = evaporator;
T/G = turbine/generator; C = condenser; CP = condensate pump;
CW = cooling water

m = mass flow rate

h_i = enthalpy at state point

h_o = enthalpy at dead state

We ignore the kinetic and potential energy difference terms relative to the enthalpy difference.

The Second Law for the system and surroundings can be expressed as:

$$0 = m(S_i - S_o) - Q/T_o$$

Entropy production 0 will be reduced to zero in the ideal limit of reversible operation, and represents the upper limit on the performance of a given initial state and final dead state for a component. For this special case, the equation above reduces to:

$$Q = m\ T_o(S_i - S_o)$$

Where:

Q = heat in

m = mass flow rate

T_o = temperature at dead state

S_i = entropy at state point

S_o = entropy at dead state

By combining the first and third equations above we obtain an expression for the maximum possible work that could be extracted from the fluid for a given initial state to the dead state. This ultimate work is called the exergy (E) and is given by:

$$E = m(h_i - h_o) - T_o(S_i - S_o)$$

The difference between the exergy and actual work is a measure of the shortcomings of a plant; it represents the work dissipated or lost by processes such as friction, turbulence, mixing and heat transfer. Any process that is thermodynamically irreversible robs the fluid of exergy and diminishes its potential to produce useful work.

Plant components may be evaluated on a Second Law basis by:

Exergy lost = exergy in - exergy out

The second term consists of exergy carried **into** the component by means of mass flow and heat flow and the third term is exergy carried **out** with mass flow and produced as work. The exergy lost is always positive.

The actual power (W)' developed by a component can now be compared with the maximum possible power (E)'. The Second Law efficiency for a given component may be defined as:

'(II) = W'/E'

The performance of the power plant as a whole can be expressed in terms of the utilization factor defined as:

$$u = W/E$$

Where W is the net electrical power delivered to the busbar and E is the exergy of the inlet geothermal fluid. The utilization factor (u) for the whole plant is the ratio of the work actually delivered to the busbar and the maximum possible work with the given thermodynamic state at the geothermal fluid inlet and the characteristics of the dead state (geofluid wellhead exergy).

The thermal efficiency of the cycle is:

$$_{th} = (h_4 - h_5) - (h_6 - h_3/(h_1 - h_2)$$

Where:

h_4 = enthalpy into turbine

h_5 = enthalpy out of turbine

h_6 = enthalpy into feed pump

h_3 = enthalpy out of feed pump

h_1 = enthalpy into evaporator

h_2 = enthalpy out of evaporator

which is not equal to the utilization factor because $T_o (S_i - S_o)$ and $h_i - h_o$ are of comparable orders of magnitude.

For example, if we wanted to judge the percentage improvement achieved by a well operating at T_i = 420°F compared with one at T_i = 220°F with heat rejection at T_o = 100°F, we would compare e = 70.64 Btu/lbm with e = 11.45 Btu/lbm and conclude that the improvement is by a factor of 6.2. On the basis of plant thermal efficiency (calculated by First Law analysis) we would compare = .22 with = .08 and conclude the improvement was by a factor of 2.8.

The difference in the comparison results from the basis of two different enthalpy differences, $(h_i - h_o)$ = 328.90 Btu/lbm in the first case and $(h_i - h_o)$ = 120.23 Btu/lbm in the second case. Though the results were consistent with the method of cycles, it does not truly rank the geothermal fluid's capability to produce electricity. The first installation would deliver about six times as much power as the second.

Actual module efficiency is:

$$= (W_t - W_{fp})/m(h_1 - h_2)$$

and overall plant efficiency is:

$$= W \text{ busbar}/m(h_1 - h_2)$$

based on measured values at the generator, feed pump and busbar.

To illustrate the Second Law Analyses method we have chosen the winter 1430 hour test data. The dead state was taken as the cooling water temperature at T_o = 61°F = 520.67R. Based on state-point data, we may summarize the analysis in the following way:

I. INPUT DATA FILE SAMPLE CALCULATION FOR STATE POINT 1.

A. Dead state: cooling water

1. Temperature, T_o = 61°F = 520.67R
2. Enthalpy, h_o = 29.06 Btu/lbm
3. Entropy, S_o = .0574 Btu/lbm °F

B. Geofluid: evaporator inlet

1. Volume flow rate, Q_2 = 118.2 ft^3/min
2. Specific volume, $_f$ = .016401 ft^3/lbm
3. Mass flow rate, m = $Q_z / _f$ = 7206.9 lbm/min
4. Temperature at evaporator inlet, T_i = 221°F
5. Enthalpy at evaporator inlet, h_i = 189.24 Btu/lbm
6. Entropy at evaporator inlet, S_i = .3256 Btu/lbm °F
7. Exergy at evaporator inlet, $E_1 = m(h_i - h_o) - T_o(S_i - S_o)$

   = 7206.9(189.24 - 29.06) - 520.67 (.3256 - .0574)

$= (148002.65 \text{ Btu/min})(.01758 \text{ kW/Btu/min})$

$= 2601.89 \text{ kW}$

The exergy of all other state points are calculated in a similar manner. Thermodynamic properties of saturated steam were published in the 1967 ASME Steam Tables, copyrighted 1967 by The American Society of Mechanical Engineers. Thermodynamic properties of R-114 were obtained from the REFRIG program, copyrighted 1985 by Software Systems Corporation.

II. SECOND LAW ANALYSIS SAMPLE CALCULATION

A. Evaporator

Exergy drop in geofluid = $E_1 - E_2$ = 2601.9 - 1479.8 kW

Exergy rise in R-114 = $E_4 - E_3$ - 51.4 = 1382.6 kW

Second Law efficiency = 1122.1/1382.6 = .93

B. Condenser

Exergy drop in R-114 = $E_5 - E_6$ = 592.0 - 21.2 = 573.8 kW

Exergy rise in cooling water = $E_7 - E_8$ = 77.9 - 0 = 77.9 kW

Second Law efficiency = .14

C. Feed Pump

Exergy rise in R-114 = $E_3 - E_6$ = 51.4 - 21.2 = 30.2 kW

Mechanical power delivered to pump = 55 kW

Second Law efficiency = .55

D. Turbine

Exergy drop, $\Delta E_t = E_4 - E_5$ = 1434.0 - 592.0 = 842.0 kW

E. Unit energy delivered per ton of geofluid

Based on turbine exergy drop = $33.33\Delta E_t/m$

= (33.33)(842.0)/7206.89 = 3.89 kWh/ton

Based on net power delivered to busbar

= 33.33 W busbar/m = (33.33)(381.8)/7206.89 = 1.77 kWh/ton

F. Mechanical power developed by turbine = 623.80 kW

Turbine internal 2nd Law efficiency = $W_t/\Delta E_t$ = 623.80/842.0

= .74

G. Net electrical power delivered to busbar 2nd Law efficiency

Based on inlet geofluid exergy = W busbar/E_1 = 381.8/2601.89 = .15

Based on geofluid exergy drop = W busbar/ΔE_{evap} = 381.8/1479.0 = .26

H. Thermal efficiency = $(h_4 - h_5) - (h_3 - h_6)/(h_1 - h_2)$

= (97.68 - 91.45) - (28.947 - 28.352)/(189.24 - 130.96) = .10

I. Actual module efficiency = $(W_t - W_{fp})/m(h_1 - h_2)$

= (568.8 - 55)/(7206.89)(.07158)(189.24 - 130.96) = .08

J. Overall plant efficiency = W busbar/$m(h_1 - h_2)$

= 381.8/(7206.89)(.01758)(189.24 - 130.96) = .05

APPENDIX C

Summer Data Test

6

ORMAT TEST LOG SHEET

Hourly Readings

* Time	10⁰⁰	11⁰⁰							verage	ax/Min
othermal Well/Pump										
-Temperature from pump	104.67	105.86								
-Pressure from pump										
-Flow from pump	5.45	5.5								
at Exchanger										
-Brine temperature IN	221	221								
-Brine pressure IN	38	37.5								
-Brine temperature OUT	166	166.5								
-Brine pressure OUT	25.5	25								
-Freon temp. (Pump OUT/H.E. IN)	86	87								
-Freon pres. (Pump OUT/H.E. IN)	146	148								
-Freon temp. (H.E. OUT/Turb. IN)	192	189								
-Freon pres. (H.E. OUT/Turb. IN)	124	126								
-Freon flow IN	5.0	4.9								
idenser										
-Cooling water temperature IN	65.5	66.5								
-Cooling water pressure IN	17.5	17.5								
Cooling water temperature OUT	81.5	82.5								
Cooling water pressure OUT	10.5	10.5								
Freon temp. (Turb. OUT/Cond. IN)	133	131								
Freon pres. (Turb. OUT/Cond. IN)	23	23								
Freon temp. (Pump IN/Cond. OUT)	84	85								
Freon pres. (Pump IN/Cond. OUT)	21	23								
Cooling water flow OUT	6.25	6.2								
erator/Turbine										
Freon pressure nozzle block	20	20								
Generator kWh output, meter read	6/28	10/48								
Freon Circulating Pump	.8 6113.5	.8 6115.5								
Running time of pump	91.79	92.79								
Cooling Water Circulation Pump										
-Temperature INTO pump										
-Pressure INTO pump										
Temperature OUT pump										
Pressure OUT pump										
unning time of pump										
y Pond										
Ambient Air Temperature	86	85								
T.W.B. upwind of pond										
T.W.B. downwind of pond										
Wind direction										
Temperature out of pond #1										
akeup water flow to pond										
unning time of pump										
unning time of pump										

end

/4-75

me of Generator Output reading

Date 8/16/85

*

ORMAT TEST LOG SHEET

Hourly Readings

Time	0200 2:00	3:00	4:00	5:00	0600 6:00	0700	0800	0900	erage	x/Min
eothermal Well/Pump										
3-Temperature from pump	92.75	97.77	99.0	97.13	100.69	101.95	102.87	103.81		
3-Pressure from pump										
1-Flow from pump	5.5	5.4	5.4	5.4	5.4	5.4	5.45	5.5		
eat Exchanger										
1-Brine temperature IN	221	221	221	221	222	221	221.5	222		
1-Brine pressure IN	38	30	38	38	38	38	38.5	38.5		
2-Brine temperature OUT	167	167	167	166	166	166	166	166		
2-Brine pressure OUT	25	15	25	25	25	25	25	25		
3-Freon temp. (Pump OUT/H.E. IN)	90	89	88	87	86	86	86	86		
3-Freon pres. (Pump OUT/H.E. IN)	144	145	143	147	145	145	145	145		
4-Freon temp. (H.E. OUT/Turb. IN)	100	190	190	190	192	192	192	192		
4-Freon pres. (H.E. OUT/Turb. IN)	124	123	123	123	125	125	123	123		
2-Freon flow IN	4.95	4.9	5.0	4.9	4.95	4.8	4.85	4.85		
ondenser										
3-Cooling water temperature IN	70	68.5	67	66.5	65.5	65	64.5	64.8		
3-Cooling water pressure IN	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5		
9-Cooling water temperature OUT	85.5	84	83	82	81	80.7	80.5	81		
9-Cooling water pressure OUT	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5		
5-Freon temp. (Turb. OUT/Cond. IN)	136	134.5	129	129	132	133	133	133		
5-Freon pres. (Turb. OUT/Cond. IN)	0	0	0	0	-0	-0	-0	-0		
7-Freon temp. (Pump IN/Cond. OUT)	89	88	87	86	84	84	84	84		
7-Freon pres. (Pump IN/Cond. OUT)	24	23	22	22	22	21.5	21	21		
3-Cooling water flow OUT	6.1	6.16	6.2	6.2	6.15	6.1	6.1	6.2		
enerator/Turbine										
5-Freon pressure nozzle block	43?	23	23	23	20	20	19	26		
2-Generator kWh output, meter read	24/5 .75 KW	24/6 .76	25/6 .80 KW	26/5 .80 KW	23/5 .5 [illegible]	23/6 .8 6013	23/5 .8 6134?	23/5 .81 6108.8		
-Freon Circulating Pump										
3-Running time of pump	82.66	84.66	85.92	86.64	87.81	88.86	89.79	90.72		
-Cooling Water Circulation Pump										
10-Temperature INTO pump										
10-Pressure INTO pump										
11-Temperature OUT pump										
11-Pressure OUT pump										
4-Running time of pump	53									
ray Pond										
15-Ambient Air Temperature	74	72	72	71	55	61	?	72		
12-T.W.B. upwind of pond										
13-T.W.B. downwind of pond										
Wind direction										
14-Temperature out of pond #1										
4-Makeup water flow to pond										
5-Running time of pump										
5-Running time of pump										

0615 - 789743
0715 - 791744
51/74-75 0815 - 793745
0915 795770

*Time of Generator Output reading

Date 8-16-85

ORMAT TEST LOG SHEET

Hourly Readings

* Time	18:00	19:00	20:00	21:00	2200	23:00	24:00	1:00	erage	x/Min
eothermal Well/Pump										
)-~~Temperature from pump~~ run time	88.84	89.86	90.89	91.96	92.39	93.14	94.76	95.73		
)-Pressure from pump										
l-Flow from pump	5.65	5.6	5.6	5.55	5.5	5.5	5.5	5.5		
eat Exchanger										
l-Brine temperature IN	221.5	221.5	221.5	221	221	221	221	221		
l-Brine pressure IN	39.5	39	39	38.5	38	38	38	30		
2-Brine temperature OUT	173	173	173	173	168	169	168	168		
2-Brine pressure OUT	25.5	25.5	25.5	25.5	25.5	25	25	25		
3-Freon temp. (Pump OUT/H.E. IN)	99.5	98	97.5	96	95	95	93	92		
3-Freon pres. (Pump OUT/H.E. IN)	155	154	154	154	144	145	144	143		
l-Freon temp. (H.E. OUT/Turb. IN)	190	190	190	190	192	190	190	190		
l-Freon pres. (H.E. OUT/Turb. IN)	137	136	136	136	124	124	123	123		
2-Freon flow IN	4.75	4.85	4.66	4.5	5.1	5.1	5.1	4.95		
ondenser										
3-Cooling water temperature IN	80	78.8	78	76	74.5	74	72.5	71		
3-Cooling water pressure IN	17.5	17.5	17.5	17.5	17.5	17.5	10	17.5		
)-Cooling water temperature OUT	98	93.5	92	90.5	91.5	89.5	88	86.5		
)-Cooling water pressure OUT	11	11	11	11	10.5	11	11	10.5		
5-Freon temp. (Turb. OUT/Cond. IN)	135	134	134	132.5	141	140	139	138		
5-Freon pres. (Turb. OUT/Cond. IN)	0	0	0	0	0	0	0	0		
7-Freon temp. (Pump IN/Cond. OUT)	96	95	95	94	93	92	91	90		
7-Freon pres. (Pump IN/Cond. OUT)	30	28	27.5	27	27	26	26	25		
3-Cooling water flow OUT	7.3	6.9	6.8	6.5	6.4	6.3	6.2	6.2		
enerator/Turbine										
5-Freon pressure nozzle block	27	26	26	25	25	25	24	24		
2-Generator kWh output, meter read	30/5	30/5	30/5	30/5	29/5	26/5	28/5	26/5		
-Freon Circulating Pump		6067		6067 ..kh	.71 kwh	.71 KA	.715 KA	.741		
3-Running time of pump	75.76	76.79	77.81	78.88	78.91	80.66	81.67	82.69		
-Cooling Water Circulation Pump						10" ...				
.0-Temperature INTO pump										
.0-Pressure INTO pump						0				
.1-Temperature OUT pump										
.1-Pressure OUT pump						22				
3-Running time of pump										
ray Pond										
.5-Ambient Air Temperature	96	90	85	82	80	75	76	76		
.2-T.W.B. upwind of pond										
.3-T.W.B. downwind of pond										
Wind direction										
.4-Temperature out of pond #1										
3-Makeup water flow to pond										
-Running time of pump										
-Running time of pump										

6" valve open @ 9:32

1/74-75

*Time of Generator Output reading

Date Thurs Aug 16 1985

3

* Time

ORMAT TEST LOG SHEET

Hourly Readings

othermal Well/Pump	10:00	11:00	12:00	1:00	2:00	3:00	1600 4:00	1700 5:00	verage	ix/Min
-Temperature from pump	80.75	81.75	—	—	84.85	85.99	86.87	87.95		
-Pressure from pump										
-Flow from pump	4.1	4.1	4.1	4.1	4.15	5.6	5.6	5.6		
at Exchanger										
-Brine temperature IN	221	221	22:1	221	221	221	221.5	221.5		
-Brine pressure IN	96.5	96.5	97	97.5	97.5	39	39	39		
-Brine temperature OUT	162	162	167.5	168	168.	173	173	173		
-Brine pressure OUT	87	87	87	88.5	87.0	25.5	255	25.5		
-Freon temp. (Pump OUT/H.E. IN)	91	93	94	96	97	98.5	99	99.5		
-Freon pres. (Pump OUT/H.E. IN)	137	136	146	147	147	154.5	156	155		
-Freon temp. (H.E. OUT/Turb. IN)	185	190	186	185	186	191	191	191		
-Freon pres. (H.E. OUT/Turb. IN)	119	120	131	131	131	139	138	138		
-Freon flow IN	5.0	5.0	4.4	4.4	4.4	4.6	4.6	4.7		
ndenser										
-Cooling water temperature IN	71.5	72.5	74.0	77.0	77.75	78.8	79.2	79.5		
-Cooling water pressure IN	17.5	17.5	17.5	18.5	17.5	17.5	17.5	17.5		
-Cooling water temperature OUT	86	88	88.5	91	91.5	93	93.5	93.8		
-Cooling water pressure OUT	10.5	10.5	11	11	10.5	11	11	10.5		
-Freon temp. (Turb. OUT/Cond. IN)	135	137	130	131	132	135	135	135		
-Freon pres. (Turb. OUT/Cond. IN)	0	0	0	-0	-1	0	0	0		
-Freon temp. (Pump IN/Cond. OUT)	89	91	90	92	94	95.5	96	96.5		
-Freon pres. (Pump IN/Cond. OUT)	25	26	25.5	27.5	27.0	29.5	29.5	30		
-Cooling water flow OUT	6.4	6.3	6.7	6.3	6.35	6.35	7.15	6.35		
nerator/Turbine										
-Freon pressure nozzle block	22	22	23	24	25.5	27	27	27		
-Generator kWh output, meter read	6035.5	6035.9	24.3/4	25.1/4	30/5	6051	30/5	30/5		
-Freon Circulating Pump	3..					5/30	605[illegible]	6659.3		
-Running time of pump	67.67	6866	69.88	70.74	71.77	72.89	73.79	74.87		
-Cooling Water Circulation Pump										
0-Temperature INTO pump	73									
0-Pressure INTO pump										
1-Temperature OUT pump										
1-Pressure OUT pump										
-Running time of pump										
ray Pond					NOTE 1					
5-Ambient Air Temperature	84	90	92	96	98	96	98	98		
2-T.W.B. upwind of pond										
3-T.W.B. downwind of pond										
Wind direction										
4-Temperature out of pond #1										
-Makeup water flow to pond										
	8.75"									
-Running time of pump										
-Running time of pump										

T.3.W T.1.W

(11:2[illegible]) 0 2 [illegible] 11.6 − 5922 4.94 (4:26−11:26)

1/74-75

([illegible]) 0 [illegible] 1.25 − 7868 6.57 (9.25 11:25)

↑ 24.3 sec / 4 cycles.

NOTE 1: operator changed brine flow at ~~well pump~~ d.tch about 2:30

*Time of Generator Output reading

Date 8-15-85

2

ORMAT TEST LOG SHEET

Hourly Readings

* Time	0200 2:00	0300 3:00	400	5:00	6:00	7:00	8:00	9:00	Average	Max/Min
Geothermal Well/Pump										
Well	72.86	73.84	74.79	75.51	76.77	77.75	78.75	79.7		
T0-Temperature from pump										
P0-Pressure from pump										
Q1-Flow from pump	4.7	4.8	4.8	4.8	5.0	5.0		4.1		
Heat Exchanger										
T1-Brine temperature IN	222	222	221	220	221	221	221	221		
P1-Brine pressure IN	60	60	60	40	60	59	60	92		
T2-Brine temperature OUT	170.5	170.5	170.5	171	171	170.5	170	162		
P2-Brine pressure OUT	48.5	48.0	49	40	48	48	48.5	86		
T3-Freon temp. (Pump OUT/H.E. IN)	94.0	93.0	93	93	92	92	91	90		
P3-Freon pres. (Pump OUT/H.E. IN)	150.0	151	151	150	150	150	151	138		
T4-Freon temp. (H.E. OUT/Turb. IN)	189.5	190	190	190	190	190	190	188		
P4-Freon pres. (H.E. OUT/Turb. IN)	135	136	136	135	136	136	136	120		
Q2-Freon flow IN	4.5	4.2	4.65	4.6	4.4	4.8	4.5	4.9		
Condenser										
T8-Cooling water temperature IN	74.5	73.7	73	73	72.2	72	72	70		
P8-Cooling water pressure IN	17.5	17.75	18	18	17.5	17.5	17.5	17.5		
T9-Cooling water temperature OUT	88.5	87.8	87.5	87	86.5	86.3	84.5	85		
P9-Cooling water pressure OUT	11.0	11.0	10.5	11	10.5	10.5	10.5	10.5		
T6-Freon temp. (Turb. OUT/Cond. IN)	131	131	131	130	130	130	129	135		
P6-Freon pres. (Turb. OUT/Cond. IN)	0	0	0	0	0	0	0	0		
T7-Freon temp. (Pump IN/Cond. OUT)	91.0	90.3	90	90	89	89	88	88		
P7-Freon pres. (Pump IN/Cond. OUT)	26.0	25.3	26	25	24	24	22.5	24		
Q3-Cooling water flow OUT	6.1	6.1	6.1	6.4	6.1	6.1	6.2	6.4		
Generator/Turbine										
P5-Freon pressure nozzle block	25	24	24	22	23	22	21	21		
E2-Generator kWh output, meter read	6012.0	6014.3	6016.5	6021.2	6023.8	6026.0	6030.6	6033.7		
				4.7	2.	4.	4.6	3.1	1.8	
-Freon Circulating Pump										
E3-Running time of pump	59.78	60.76	61.71	62.73	63.69	64.66	65.64	66.63		
-Cooling Water Circulation Pump										
T10-Temperature INTO pump				71						
P10-Pressure INTO pump				0						
T11-Temperature OUT pump		70								
P11-Pressure OUT pump		22		22						
E4-Running time of pump										
Spray Pond spray		10		18/64						
T15-Ambient Air Temperature	56	60	56	56	58	60	70	82		
T12-T.W.B. upwind of pond				56						
T13-T.W.B. downwind of pond				64						
-Wind direction										
T14-Temperature out of pond #1										
Q4-Makeup water flow to pond										
water level pipe inlet				7½"						
E5-Running time of pump										
E6-Running time of pump										

4:07 - water gain on Q2

2750 @ 5:07 - Q2 - 4.58 .001667

2704 @ 5:12 - 6:12 4.51 (gain of 25%)

2600 @ 7:10 - 4.33

[illegible] 7:20 = 4.73

5063 @ 8:20

951/74-75

*Time of Generator Output reading (See Note over)

Date 8-15-85

First Test Results *

ORMAT TEST LOG SHEET

Hourly Readings

Time	1800 6:00	1900 7:00	2000 8:00 PM	2100 9:00	2200 10:00	11:15	2400 12:00	0100 1:00 a.m.	Average	...x/Min
eothermal Well/Pump										
RUN TIME	65.66	66.60	67.75	68.72	69.72	✓	70.85	71.83		
)-Temperature from pump										
)-Pressure from pump										
-Flow from pump	4.8	4.8	4.8	4.75	4.8	5.1	4.8	4.7	4.78	
eat Exchanger						(11:26 228)				
1-Brine temperature IN	221	221	221.5	221.5	222	218	222	222		
1-Brine pressure IN	64	64	65	64.5	64.5	59	60	60		
2-Brine temperature OUT	171	171	171	171	170.5	171	171	170.5		
2-Brine pressure OUT	53	53	53	53.5	53.0	48	48	48		
3-Freon temp. (Pump OUT/H.E. IN)	99	98	97	97	96	92	95	94.5		
3-Freon pres. (Pump OUT/H.E. IN)	153	152	151	151	151	151	151	150		
4-Freon temp. (H.E. OUT/Turb. IN)	188	188	188	188	188.5	188.0	189	189		
4-Freon pres. (H.E. OUT/Turb. IN)	137	137	136	136.5	136.0	136	136	136		
2-Freon flow IN	5.0	5.0	4.6	4.5	4.2	4.7	4.7	4.7		
ondenser										
3-Cooling water temperature IN	79	76	77	77.5	77.0	74.5	75.5	75.0		
3-Cooling water pressure IN	17	18	17.5	18.0	17.7	17.5	18.0	17.75		
)-Cooling water temperature OUT	93	94	93	91.0	91.0	87.8	89.5	89.5		
)-Cooling water pressure OUT	10	10.5	10.5	11.0	10.7	11.0	11.0	11.0		
5-Freon temp. (Turb. OUT/Cond. IN)	134	133	133	132	132	131	132	132		
5-Freon pres. (Turb. OUT/Cond. IN)	2	2	1	0	0	0	0	0		
7-Freon temp. (Pump IN/Cond. OUT)	96	94	94	95	94	91	92	92.5		
7-Freon pres. (Pump IN/Cond. OUT)	27	27	28	28	28	26.5	27	26		
3-Cooling water flow OUT	6.6	6.3	6.4	6.2	6.3	6.2	6.2	6.1		
enerator/Turbine										
5-Freon pressure nozzle block	26	27	27	26.5	26.0	22.0	26.0	26.0		
2-Generator kWh output, meter read	5991	5993.0	5995.3	5998.0	6002.7	6003.5	6004.2	6007.3	6012	6014
		2.7	1.5	2.7	4.7	.8		3.1	4.7	2.0
-Freon Circulating Pump										
3-Running time of pump	51.75	52.69	53.82	54.81	55.81	✓	57.77	58.76		
-Cooling Water Circulation Pump					(10:18					
10-Temperature INTO pump										
10-Pressure INTO pump		0					0			
11-Temperature OUT pump					78		77			
11-Pressure OUT pump					22		21.5			
-Running time of pump										
ray Pond SPRAY WATER		76			10:45 62		12:21 70			
5-Ambient Air Temperature		88			71.3		64	63		
2-T.W.B. upwind of pond										
3-T.W.B. downwind of pond										
Wind direction										
4-Temperature out of pond #1										
-Makeup water flow to pond										
-Running time of pump										
-Running time of pump										

Rel hu. 15.15

1/74-75 — unit down at 10:20,
restart at 11:10
on line at 11:12

:Time of Generator Output reading

Date 8-14-85/8-15-85

APPENDIX D

Fall Data Set

ORMAT TEST LOG SHEET

Hourly Readings Wed Oct 16, 1985

* Time	0600	0700	0850	9:00	10AM	11AM	12 Noon	1 PM		
Geothermal Well/Pump										
T0-Temperature from pump										
P0-Pressure from pump										
Q1-Flow from pump	4.0	4.05	4.5	4.55	4.75	4.95	4.95	4.9		
Heat Exchanger										
T1-Brine temperature IN	220	220	220	220	220	221	220	220		
P1-Brine pressure IN	17	17	17	17	17.5	17.5	17	17		
T2-Brine temperature OUT	161	161	161	161	161	161	162	164		
P2-Brine pressure OUT	0.5	0.5	0.5	0.5	0.5	0.5	0.75	0.8		
T3-Freon temp. (Pump OUT/H.E. IN)	75	70	77	77	77.5	78.0	79	80		
P3-Freon pres. (Pump OUT/H.E. IN)	139	138	130	139	139	141	142	141		
T4-Freon temp. (H.E. OUT/Turb. IN)	194	194	194	194	194	194	194	194		
P4-Freon pres. (H.E. OUT/Turb. IN)	118	118	117	117	117	118	118	118		
Q2-Freon flow IN	4.3	4.5	4.25	4.30	4.70	4.75	4.7	4.85		
Condenser										
T8-Cooling water temperature IN	52	52	52.5	52	52.5	52	53	54		
P8-Cooling water pressure IN	17.5	18	18	18	17.8	17.8	17.8	17.8		
T9-Cooling water temperature OUT	70	69	69	69	69.5	70.5	71.5	72.5		
P9-Cooling water pressure OUT	10	10	10	10	10	10	10	10		
T6-Freon temp. (Turb. OUT/Cond. IN)	134	134	134	133.5	134	134	135	135		
P6-Freon pres. (Turb. OUT/Cond. IN)	24	26	26	30	32	31	32	35		
T7-Freon temp. (Pump IN/Cond. OUT)	70	78	78	77	77	77	78	78		
P7-Freon pres. (Pump IN/Cond. OUT)	23	22	23	23	23	24	24	25		
Q3-Cooling water flow OUT	6.0	5.75	5.9	5.95	5.95	6.0	6.0	6.0		
Generator/Turbine										
P5-Freon pressure nozzle block										
E2-Generator kWh output, meter read	20.3/5	20.7/5	20.4/5	20.5/5	20.6/5	20.8/5	20.9/5	21.2/5		
-Freon Circulating Pump WELL	1347.8	1348.73	1349.14	1350.66	1351.67	1352.67	1353.72	1354.54		
E3-Running time of pump FREON	1374.17	1375.63	1376.30	1377.17	1378.38	1379.39	1380.42	1381.42		
-Cooling Water Circulation Pump										
T10-Temperature INTO pump										
P10-Pressure INTO pump										
T11-Temperature OUT pump										
P11-Pressure OUT pump										
E4-Running time of pump										
Spray Pond WET	58	32	36	40	48	51	51	54		
DRY	30	30	38	43	52	60	64	68		
T15-Ambient Air Temperature										
T12-T.W.B. upwind of pond										
T13-T.W.B. downwind of pond										
Wind direction										
T14-Temperature out of pond #1										
Q4-Makeup water flow to pond										
E5-Running time of pump										
E6-Running time of pump										

662.1 671.1 664.6 663.1

(633.3 .93) (659.2 .93)

(658.2 .91) (662.3 .93) (663.0 .93) (665.4 .93)

KWH METER READINGS:

KWH = Dial Readings x 160

$$KW = \frac{\text{No Disk Revs} \times 3600 \times 4.8 \times 160}{\text{Time In Secs For No Of Disk Revs}}$$

5307 WFAFAIL

5359.614

951/74-75

*Time of Generator Output reading

Date WED 10-16-85

ORMAT TEST LOG SHEET

Hourly Readings

* Time	10:00	11:00	12:00	01:00	0200	0300	0400	0500	Range	Min.
Geothermal Well/Pump										
-Temperature from pump										
-Pressure from pump										
-Flow from pump	4.23	4.15	4.23	4.20	4.40	4.40	4.0	3.15		
Heat Exchanger										
1-Brine temperature IN	221	221	221	220	220	220	220	220		
1-Brine pressure IN	17	17	17	17	17.5	17	17	17		
2-Brine temperature OUT	162	161	161	161	162	162	161	161		
2-Brine pressure OUT	0.5	0.5	0.5	0.5	0.5	0.5	0.5	–		
3-Freon temp. (Pump OUT/H.E. IN)	82	81	81	80	80	80	80	78		
3-Freon pres. (Pump OUT/H.E. IN)	140	140		141		140	140	139		
4-Freon temp. (H.E. OUT/Turb. IN)	194	194	194	192	190	194	194	194		
4-Freon pres. (H.E. OUT/Turb. IN)	110	110	118	118	118	118	118	118		
Q2-Freon flow IN	4.6	4.50	4.5	4.5	4.35	4.3.	4.1	4.26		
Condenser										
T8-Cooling water temperature IN	55.5	55	54.5	55.0	54	53.5	53.0	52.0		
P8-Cooling water pressure IN	17.5	18	18.	18	18	18	18	17.5		
T9-Cooling water temperature OUT	74	73	73	73	72.5	71.5	71.0	71.0		
P9-Cooling water pressure OUT	10	10	10	10	10	10	10	10		
T6-Freon temp. (Turb. OUT/Cond. IN)	135.5	135	135	136	135	134	134	134		
P6-Freon pres. (Turb. OUT/Cond. IN)	21	21	22	20	20	22	24	23		
T7-Freon temp. (Pump IN/Cond. OUT)	81	80	79	78	80	79.5	79.0	79.0		
P7-Freon pres. (Pump IN/Cond. OUT)	25	25	25	22	22	24	24	24		
Q3-Cooling water flow OUT	6.0.	5.9	5.9	6.0	5.95	5.9	5.9	5.95		
Generator/Turbine										
P5-Freon pressure nozzle block										
E2-Generator kWh output, meter read	21.0/5	21.5/5	21.9/5	[illegible]	[illegible]	20.9/5	21.0/5	20.9/5		
-Freon Circulating Pump (WELL)	1339.61	1340.55	1341.70	1342.7	1343.1	1344.70	1345.65	1346.67		
E3-Running time of pump (FREON)	1366.32	1367.68	1368.41	1369.9	1370.5	1371.40	1372.30	1373.89		
-Cooling Water Circulation Pump										
T10-Temperature INTO pump										
P10-Pressure INTO pump										
T11-Temperature OUT pump										
P11-Pressure OUT pump										
E4-Running time of pump										
Spray Pond WET US	38	34	38	32.0	32.5	29	30	30		
Spray Pond DRY DS	44	39	35	39.5	34	31	30	30		
T15-Ambient Air Temperature										
T12-T.W.B. upwind of pond										
T13-T.W.B. downwind of pond										
Wind direction										
T14-Temperature out of pond #1										
Q4-Makeup water flow to pond										
E5-Running time of pump										
E6-Running time of pump										

639.1 649.9 kW 652.1 655.1

TJW/AJJ TJW/AJJ

633.4 .74 (10:00) 637.3 .74 (11:00) 639.4 .74 (12:00) 641.2 .74 645 .73

KWH METER READINGS:

KWH = Dial Readings x 160

2764800

$$KW = \frac{\text{No Disk Revs} \times 3600 \times 4.8 \times 160}{\text{Time In Secs For No Of Disk Revs}}$$

951/74-75

*Time of Generator Output reading

Date 10/15–10/16/85

* ORMAT TEST LOG SHEET

Hourly Readings Tues Oct 15, 1985

* Time	11:00 am	1:00 pm	2:00 pm	3:00 pm	4 pm	5 PM	6 PM	7:00	8:00	9:00 PM
Geothermal Well/Pump										
T0-Temperature from pump										
P0-Pressure from pump										
Q1-Flow from pump	4.25	4.8	5.0	5.0	5.12	5.05	4.85	4.60	4.8	4.7
Heat Exchanger										
T1-Brine temperature IN	220	220	221	220	220	220	220	220	220	220
P1-Brine pressure IN	26	26	25.5	17	17	17.5	17.5	17	17	17
T2-Brine temperature OUT	160	160	160	162	162	162	162	161.5	162	162
P2-Brine pressure OUT	10	10	10	—	2?	2?	1?	—	—	0
T3-Freon temp. (Pump OUT/H.E. IN)	×	80	80	81	82	82	82	82	82	82
P3-Freon pres. (Pump OUT/H.E. IN)	×	140	140	141	140	140	140	140	140	130
T4-Freon temp. (H.E. OUT/Turb. IN)	195	195	194	195	194	194	194	194	193	193
P4-Freon pres. (H.E. OUT/Turb. IN)	×	113	115	117	117	117	117	117	117	117
Q2-Freon flow IN	4.5	4.45	4.45	4.85	4.7	4.73	4.70	4.65	4.55	4.60
Condenser										
T8-Cooling water temperature IN	53	53.5	54.5	55.5	56.0	56.5	56.0	55	55.8	55.8
P8-Cooling water pressure IN	18	16	17.8	17.5	17.8	17.8	17.8	17.8	18.0	18
T9-Cooling water temperature OUT	70	71.5	72.5	74	74.3	74.7	74.2	74.2	74.2	74.2
P9-Cooling water pressure OUT	10	10	10	10	10	10	10	10	10	10
T6-Freon temp. (Turb. OUT/Cond. IN)	133	135	135	136	135.5	136	135.5	135	135	135
P6-Freon pres. (Turb. OUT/Cond. IN)	×	20	20	22	20	19	18	17	17	21
T7-Freon temp. (Pump IN/Cond. OUT)	78	78	79	80	80.5	80.5	80.2	81	81	81
P7-Freon pres. (Pump IN/Cond. OUT)	~~76~~	24	25	25	25	25	25	25	25	25
Q3-Cooling water flow OUT	5.8	6.05	6.15	6.0	6.1	6.1	6.25	6.0	6.0	6.0
Generator/Turbine										
P5-Freon pressure nozzle block										
E2-Generator kWh output, meter read		20.8/5	20.7/5	21.5/5	21.5/5	21.7/5	21.6/5	21.6/5	21.4/5	21.6/5
-Freon Circulating Pump WELLPUMP	1328.75	1330.56	1331.65	1332.64	1333.67	1334.67	1335.67	1336.67	1337.69	1338.68
E3-Running time of pump	1355.45	1357.37	1358.36	1359.35	1360.35	1361.33	1362.36	1363.40	1364.40	1365.38
-Cooling Water Circulation Pump										
T10-Temperature INTO pump										
P10-Pressure INTO pump										
T11-Temperature OUT pump										
P11-Pressure OUT pump										
E4-Running time of pump										
~~Spray Pond~~ Grain Tank WB			48	48	48	48	45	44	44	48
DB			64	64	64	64	57	53	48	45
T15-Ambient Air Temperature										
T12-T.W.B. upwind of pond										
T13-T.W.B. downwind of pond										
Wind direction										
T14-Temperature out of pond #1										
Q4-Makeup water flow to pond										
E5-Running time of pump										[illegible]
E6-Running time of pump										

646kW 640.5 638.2 642.97 637.05 640.8 640.0 635.3 638.9

6621 15 21.15 1.6

KWH METER READINGS: 638.6 .94 (4) 639.8 .94 (5) 630.7 .94 (6) 631.9 .93 (7) 631.6 .94 (8) 631.4 .94 (9)

KWH = Dial Readings x 160

$$\text{~~KW~~ W} = \frac{\text{No Disk Revs} \times 3600 \times 4.8 \times 160}{\text{Time In Secs For No Of Disk Revs}}$$

951/74-75

*Time of Generator Output reading

Date

APPENDIX E

Winter Data Set

ORMAT TEST LOG SHEET 3/6/86

Hourly Readings

* Time	0730	0730	0830	0930	10:30	11:30	12:31	13:30	14:30	15:30	(Average / Min)
Geothermal Well/Pump											
-Temperature from pump		223				223					
-Pressure from pump		23				23					
-Flow from pump	5.5	5.5	5.5	5.6	5.7		5.8	5.95	5.9	5.9	5.75
Bubbler psi		32				32					
Heat Exchanger											
1-Brine temperature IN	220	221	221	221	221	221	221 224	221 224	221 225	221	221
1-Brine pressure IN	—	—	—	—	—	—					
2-Brine temperature OUT	163	163	163	163	163	163	163	164	163	163	163
2-Brine pressure OUT	4	4	4?	4?	4?	4?	4	4	4	4	4
3-Freon temp. (Pump OUT/H.E. IN)	84	84	84	84	85	85	85	87	81	86	86.5
3-Freon pres. (Pump OUT/H.E. IN)	140	140	140	140	140	140	140	140	141	140	140
4-Freon temp. (H.E. OUT/Turb. IN)	189	188	187	187	188	188	187	187	187	186	186
4-Freon pres. (H.E. OUT/Turb. IN)	118	118	119	118	118	118	116	116	116	116	117
2-Freon flow IN	6.5	6.5	6.6	6.6	6.8	7.0	7.1	7.0	7.1	7.2	79.5
Condenser											
8-Cooling water temperature IN	56.8	56.8	56.9	57.2	57.8	59.5	59	59.5	60	60	60
8-Cooling water pressure IN	20	20	20	20	20	20	19.5	19	19	19	19
9-Cooling water temperature OUT	76	76	76	76.5	77	78	78.5	79	79	79.5	78.5
9-Cooling water pressure OUT ?	4	11	11	11.5	11	11	12	11	11	11.5	11
6-Freon temp. (Turb. OUT/Cond. IN)	134	134	134	134	134	134	134	134.5	134	134	134
6-Freon pres. (Turb. OUT/Cond. IN)	27	27	28	28	28	29.5	28.5	29.5	29.5	29	29
7-Freon temp. (Pump IN/Cond. OUT)	83	83	82.5	83	84	84.5	85	85	84.5	85	85
7-Freon pres. (Pump IN/Cond. OUT)	28	28	29	28.5	28.5	29	29	29.5	29.5	30	30
3-Cooling water flow OUT	5.0	5.6	5.6	5.6	5.6	5.6	5.7	5.75	59	5.9	5.95
Generator/Turbine											
5-Freon pressure nozzle block		23.86	23.9	24.04	24.17	24.39					
2-Generator kWh output, meter read		/5	/5	/15	/15	/15	5	5			
~~Freon Circulating~~ Pump well		4335	4336	4337	4337	4339	4340	4340	4341.88	4342.86	4343.8
3-Running time of pump Freon	4354	4355	4356	4357	4358	4359.	4360	4361	4362.15	4363.15	4364.16
-Cooling Water Circulation Pump											
10-Temperature INTO pump											
10-Pressure INTO pump											
11-Temperature OUT pump											
11-Pressure OUT pump											
4-Running time of pump											
AMBIENT WB		42	44	46	62	64	56	54	54	54	57
~~Spray Pond~~ Grain Tank DB		43	47	60	54	57	70	67	68	62	64
15-Ambient Air Temperature											
12-T.W.B. upwind of pond DB		~~49~~									
13-T.W.B. downwind of pond WB		~~42~~									
Wind direction upper meter						1885	2296	2666	3038	3408	3781
~~14-Temperature out of pond~~ KX Kuhcount					040647	040544	41070	041271	41462	41645	41844
~~4-Makeup water flow to pond~~ kwh in					064	064	064	64	64	64	64
time					10:40	11:40	12:42	1343	1440	15[illegible]	1640
~~5-Running time of well pump~~	4335	4335									
~~6-Running time of pump~~											
KW		579.62	574.41	574.40	571.95	566.79	561.95	561.95	560.84	25.40	251

KWH METER READINGS:

KWH = Dial Readings x 160

$$KW = \frac{\text{No Disk Revs} \times 3600 \times 4.8 \times 160}{\text{Time In Secs For No Of Disk Revs}}$$

* Time of Generator Output reading

951/74-75

Date

ORMAT TEST LOG SHEET 3/6/86

Hourly Readings

* Time	16 30	1730	18.30	19.30	2030	[illegible]	2230	2330	erage	t/Min
othermal Well/Pump										
-Temperature from pump										
-Pressure from pump										
-Flow from pump	5.75	5.75	6.25	5.5	5.7	5.6	5.6	5.6		
at Exchanger										
-Brine temperature IN	221	221	221	220	221	220	220	220		
-Brine pressure IN	—	—	—							
-Brine temperature OUT	163	163	163	163	163	163	163	163		
-Brine pressure OUT	4	4	4	4	4	[illegible]	4	4		
-Freon temp. (Pump OUT/H.E. IN)	86.5	85	86	86	85.5	86	86	86		
-Freon pres. (Pump OUT/H.E. IN)	140	140	140	140	140	140	140	140		
-Freon temp. (H.E. OUT/Turb. IN)	186	186	187	186	186	186	186	186		
-Freon pres. (H.E. OUT/Turb. IN)	117	115	118	110	110	118	119	119		
-Freon flow IN	7.05	6.9	6.9	6.9	6.9	6.9	6.0	6.9		
ndenser										
-Cooling water temperature IN	60	60	60	59	59	59	58.5	53.5		
-Cooling water pressure IN	19	19	19.5	19.5	19.5	19.5	19.5	19.5		
-Cooling water temperature OUT	79.5	79	79	78.5	78	78	78	78		
-Cooling water pressure OUT	11	11	11.5	11.5	11.5	11.5	11.5	11.5		
-Freon temp. (Turb. OUT/Cond. IN)	134	134	134	134	134	138	135	134		
-Freon pres. (Turb. OUT/Cond. IN)	29	28.5	29	28.5	28.5	28.5	28.5	28.5		
-Freon temp. (Pump IN/Cond. OUT)	85	85.5	85	85.5	85	86	85	84		
-Freon pres. (Pump IN/Cond. OUT)	30	29.5	29.5	29.5	29.5	29.5	29.5	29		
-Cooling water flow OUT	5.95	5.95	5.8	5.8	5.8	5.6	5.7	5.6		
nerator/Turbine										
5-Freon pressure nozzle block										
2-Generator kWh output, meter read										
-Freon Circulating Pump	4343.88	4344.87	4345.81	4346.[illegible]	4347.79	4349.0	4349.9	4350.16		
3-Running time of pump	4364.18	4365.14	4816.19	4467.1	4365.04	4369.29	4310.5	4371.05		
-Cooling Water Circulation Pump										
10-Temperature INTO pump										
10-Pressure INTO pump										
11-Temperature OUT pump										
11-Pressure OUT pump										
4-Running time of pump	51	50	47	47	48	[illegible]	42	43		
pray Pond	57.64	62	[illegible]	47	57	[illegible]	46	46		
15-Ambient Air Temperature										
12-T.W.B. upwind of pond										
13-T.W.B. downwind of pond										
Wind direction	58[illegible]	[illegible]127	4973	4959	5355	5752	6146	6530		
14-Temprature out of pond #1	[illegible]	[illegible]	42223	42422	42618	42820	43010	43220		
4-Makeup water flow to pond	64	[illegible]	[illegible]	64	64	64	64	64		
	1640	1740	1840	1940	2040	2140	2240	2340		
5-Running time of pump										
6-Running time of pump										
K.W.	532.74	860.36	55.9		56.2	567.3	560.4	560		

24.E[illegible] 24.6[illegible] 2437 24.25 24.19

KWH METER READINGS:

KWH = Dial Readings x 160

$$KW = \frac{\text{No Disk Revs} \times 3600 \times 4.8 \times 160}{\text{Time In Secs For No Of Disk Revs}}$$

*Time of Generator Output reading

951/74-75

Date

ORMAT TEST LOG SHEET 3/7/86

Hourly Readings

* Time	0030	0130	0230	0330	0430	0530	0630	0730	erage	/Min
othermal Well/Pump										
-Temperature from pump										
-Pressure from pump										
-Flow from pump	5.5	5.55	5.55	5.6	5.70	5.60	5.5	565		
at Exchanger Baldor psi										
-Brine temperature IN	221	221	221	221	225	225	221	221		
-Brine pressure IN	—	—	—	—	—	—	—	—		
-Brine temperature OUT	163	163	163	163	165	163	163	163		
-Brine pressure OUT	4?	4?	4?	4?	4	4	4	4		
-Freon temp. (Pump OUT/H.E. IN)	85.5	85.5	85	85	85	85	85	85.5		
-Freon pres. (Pump OUT/H.E. IN)	140	140	140	140	141	141	140	140		
-Freon temp. (H.E. OUT/Turb. IN)	187	187	187	187	187	187	187	187		
-Freon pres. (H.E. OUT/Turb. IN)	118	118	118	118	116	117	116	116		
-Freon flow IN	6.9	6.6	6.8	6.7	6.7	6.7	6.6	6.6		
ndenser										
-Cooling water temperature IN	58.5	58	58	58	57.5	57.5	57.5	57.5		
-Cooling water pressure IN	19.5	20	20	20	20	20	19.5	19.5		
-Cooling water temperature OUT	77.5	77.5	77	77	77	77	76.5	76.5		
-Cooling water pressure OUT	12	11.5	11.5	12	12	12	12	12		
-Freon temp. (Turb. OUT/Cond. IN)	134	134	134	134	135	135	134	134		
-Freon pres. (Turb. OUT/Cond. IN)	28	28	28	28	28	28	27.5	27.5		
-Freon temp. (Pump IN/Cond. OUT)	84	84	84	84	84	84	84	84		
-Freon pres. (Pump IN/Cond. OUT)	29	28.5	29	28.5	28.5	28.5	28.5	28		
-Cooling water flow OUT	5.6	5.55	5.55	5.56	5.60	5.7	58.5	55		
nerator/~~Turbine~~ Time/5 revs	24.20/5	24.19/5	24.03/5	24.08/5	2406/5	24.19/5	24.23/5	2401/5		
T/F KW	138.5	176.5	177	177	178.1	177.1	176.8	179.5		
~~-Freon pressure nozzle block~~ Volt	287	288	287	289	287	287	287	287		
-Generator kWh output, meter ~~read~~ Amp	234	236	236	236	238	237				
~~-Freon Circulating~~ Pump well					4356	4357	4357.8	4358.75		
~~-Running time of~~ pump Feed					4376	4377	4378.1	4379.0		
-Cooling Water Circulation Pump										
0-Temperature INTO pump										
0-Pressure INTO pump										
1-Temperature OUT pump										
1-Pressure OUT pump										
-Running time of pump										
~~cay Pond~~ Ambient Air WB	42	44	43	42	45	42	44	46		
DB	44	45	44	45	53	48	52	52		
5-Ambient Air Temperature										
2-T.W.B. upwind of pond										
3-T.W.B. downwind of pond										
Max kW			412.6	412.6	412.6	412.6	?	?		
~~-Wind direction~~ upper meter	6938	7387	7744		88581	88842	6-0?-10	6-1135		
4-Temperature out of pond #1 kwh out	043405	043604	043802	04403	44223	44362	44600	44780		
-Makeup water flow to pond kwh in	064	064	064	064	064	064	064	064		
time	0040	0140	0240	0340	0445	0530	06:40	07:40		
-Running time of pump										
-Running time of pump										
KW	569.12	571.24	573.85	574.01	574.56	571.48	570.33	575.76		

?.out ... 0030 8 KA 195 V | 0130 same | 0230 same | 0330 same | 247 kwh 2295

KWH METER READINGS:

KWH = Dial Readings x 160

$$KW = \frac{\text{No Disk Revs} \times 3600 \times 4.8 \times 160}{\text{Time In Secs For No Of Disk Revs}}$$

:Time of Generator Output reading

951/74-75

Date

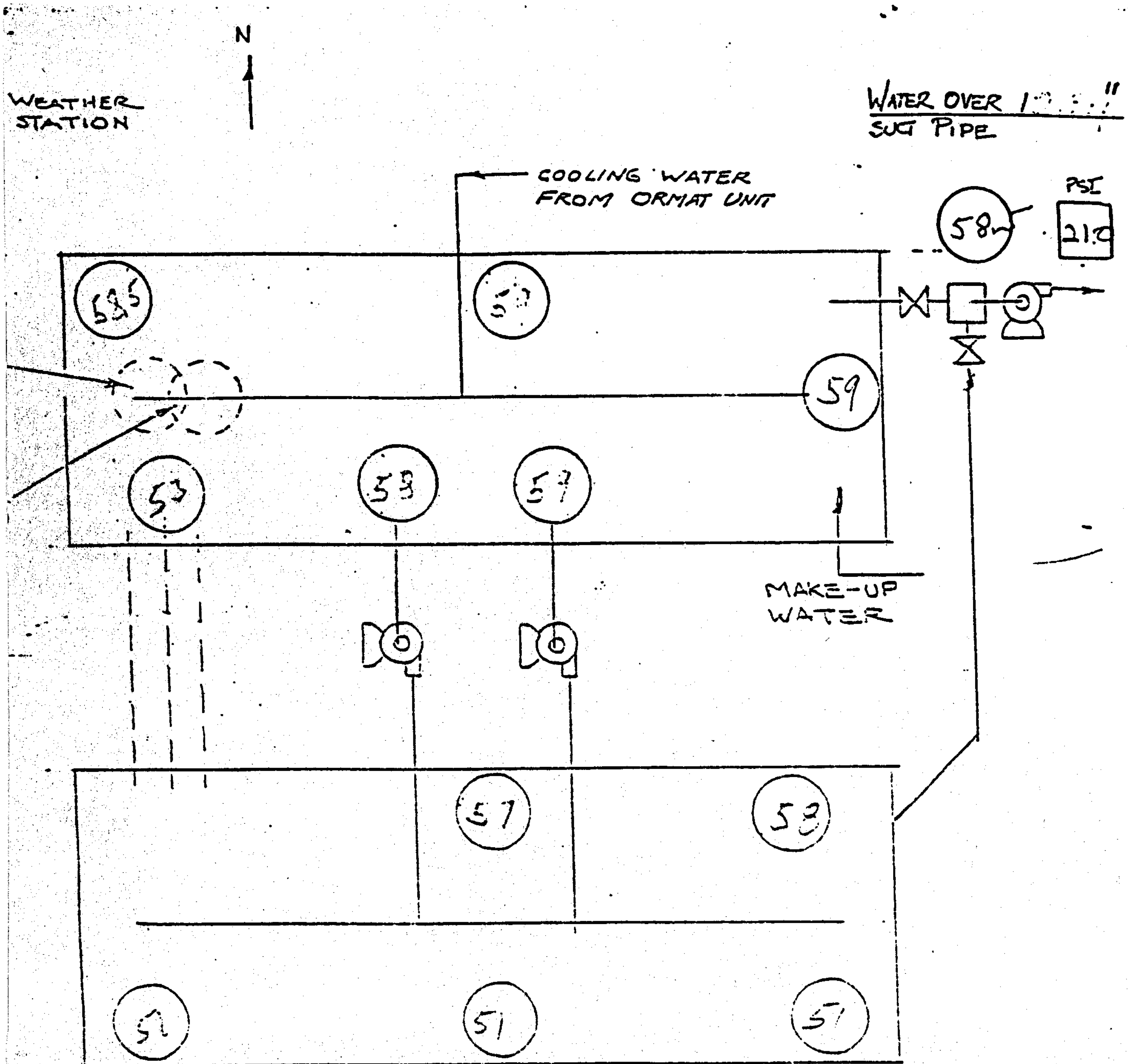
APPENDIX F

Spray Pond Data Sets

(Temp H2O in) - (Wet Bulb Temp)

SUMMARY OF SPRAY POND DATA

DB	WB	Pond Temp In	Temp Out	First Pond	Second Pond	Spray Temp	Overall Avg Spray Temp	Temp In - Spray Temp	Spray Temp - WB Temp.
64	48	72	54	64	59	61	60	9	13
63	48	74	56	63	58	63	62.5	11	15
66	52	75	56	64	58	63	64	12	11
53	44	74	56	60	58	50	56	24	6
43	39	74	55	60	57	56	61	18	17
37	34	73	55	60	55	57	57	16	23
34	32.5	72	54	59	55	52.5	51	21	20
30	30	71	53	58	54	52	55	19	22
30	32	69	52	57	53	54	—	15	22
56	52	69	52	57	53	54	56	15	2
58	50	71	57	59	54	58	60	13	8
68	54	73	54	62	57	63	65	10	11
43	42	76	57	62	57	57	60	19	15
54	48	76	57	63	58	60	65	16	12
62	54	78	58.5	66	60	58	63	20	4
70	56	79	59.5	66	60	56	58	23	0
68	54	79	60	66	61	57	57	22	3
64	51	79	60	65	60	56	55	23	5
57	47	79	59	63	59	56	66	23	19
54	43	78	59	63	59	60	64	18	17
46	43	78	59	63	58	56	62	22	13
48	44	77	58	63	58	54	60	23	10
48	44	77	58	63	57.5	54	64	23	20
52	45	77	58	63	57	50	57.4	27	18
52	46	77	58	62	57	51	51.3	26	5
52	45 AVG	75	56	62	57	56	59	19	17

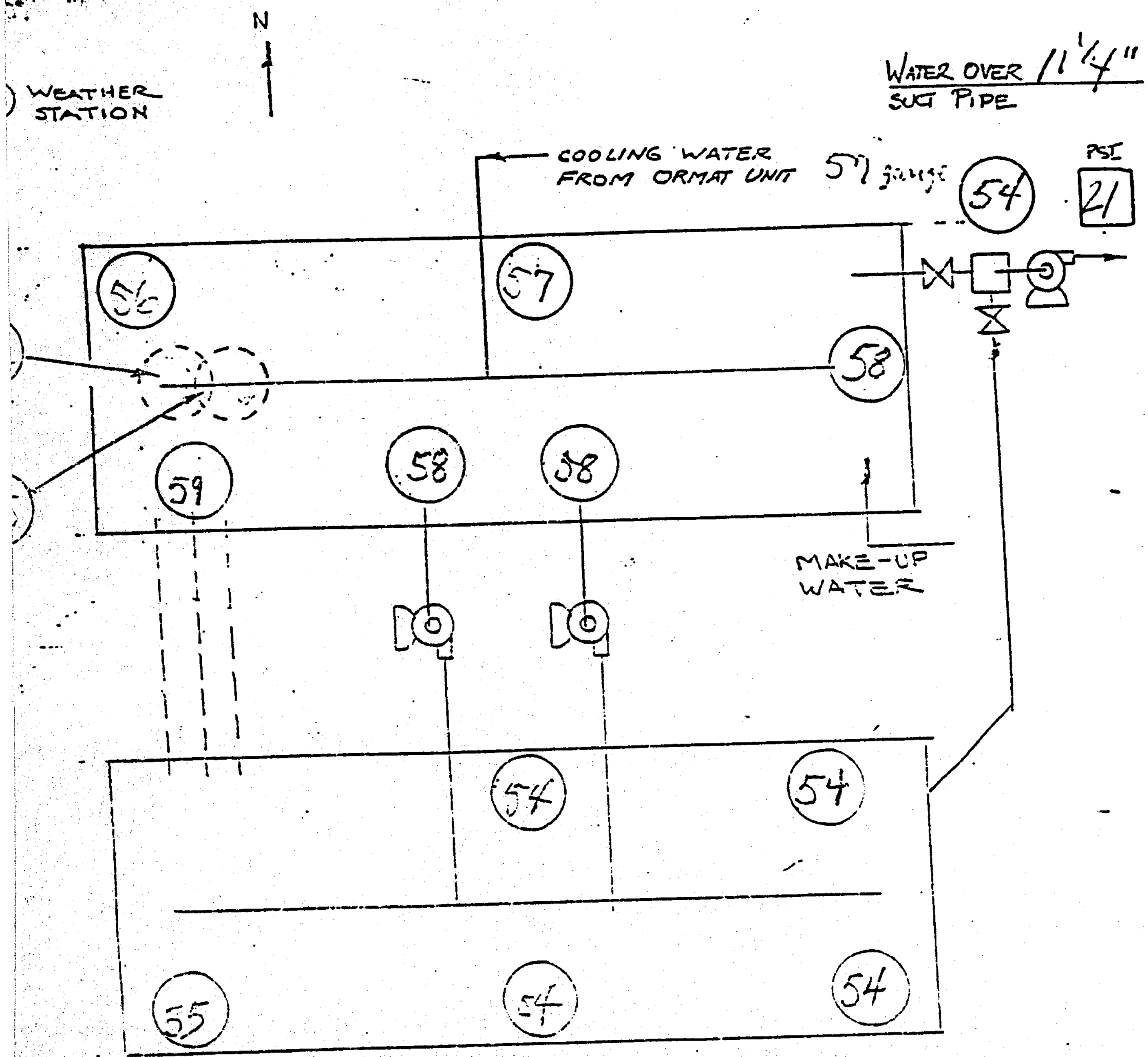


DATE: 10-16-85

TIME: 01:26

AMB. TEMP

Dir 231.1°

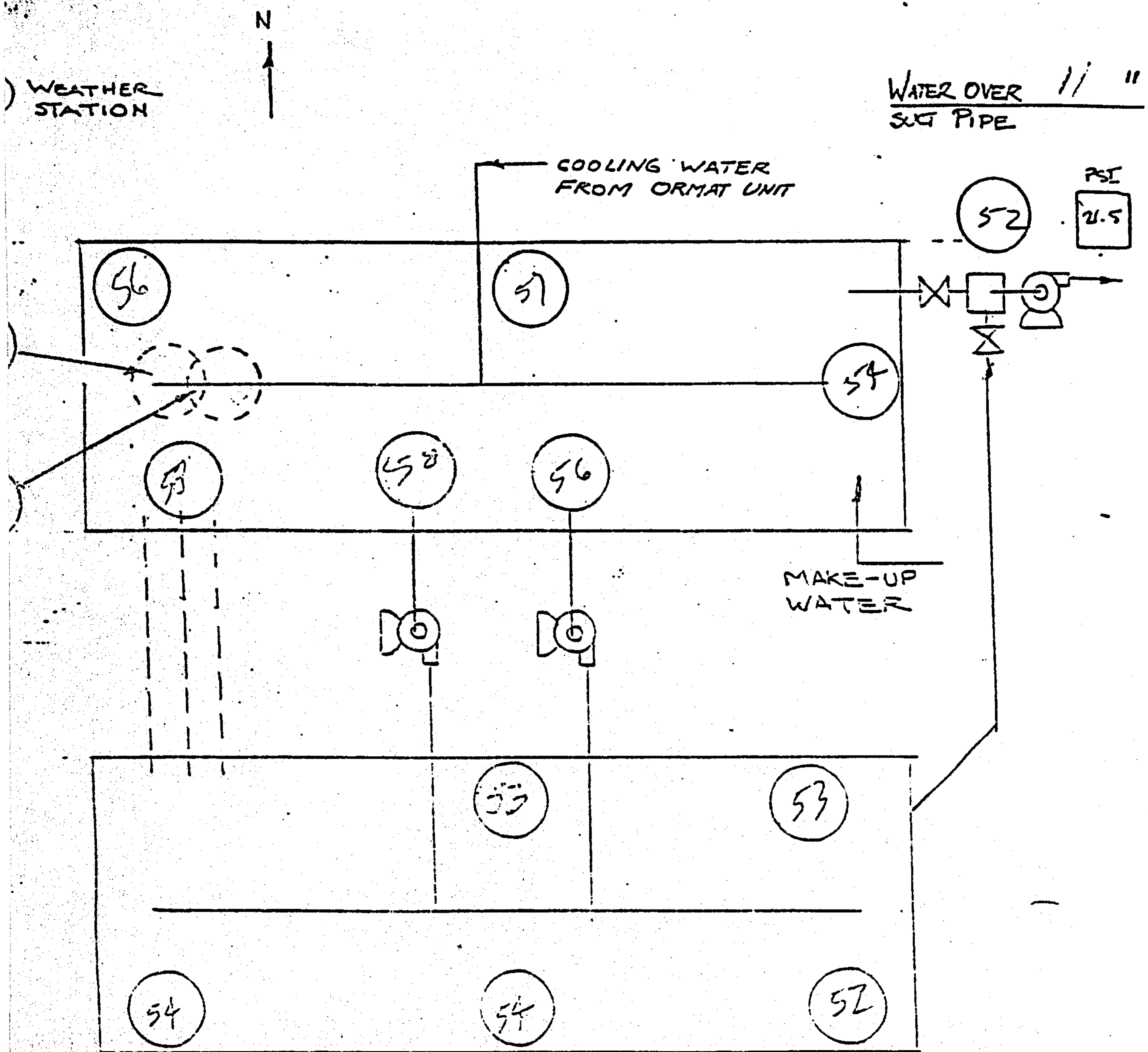


DATE: 10-16-85

by T. White / H. J[illegible]

TIME: 4:15 a.m

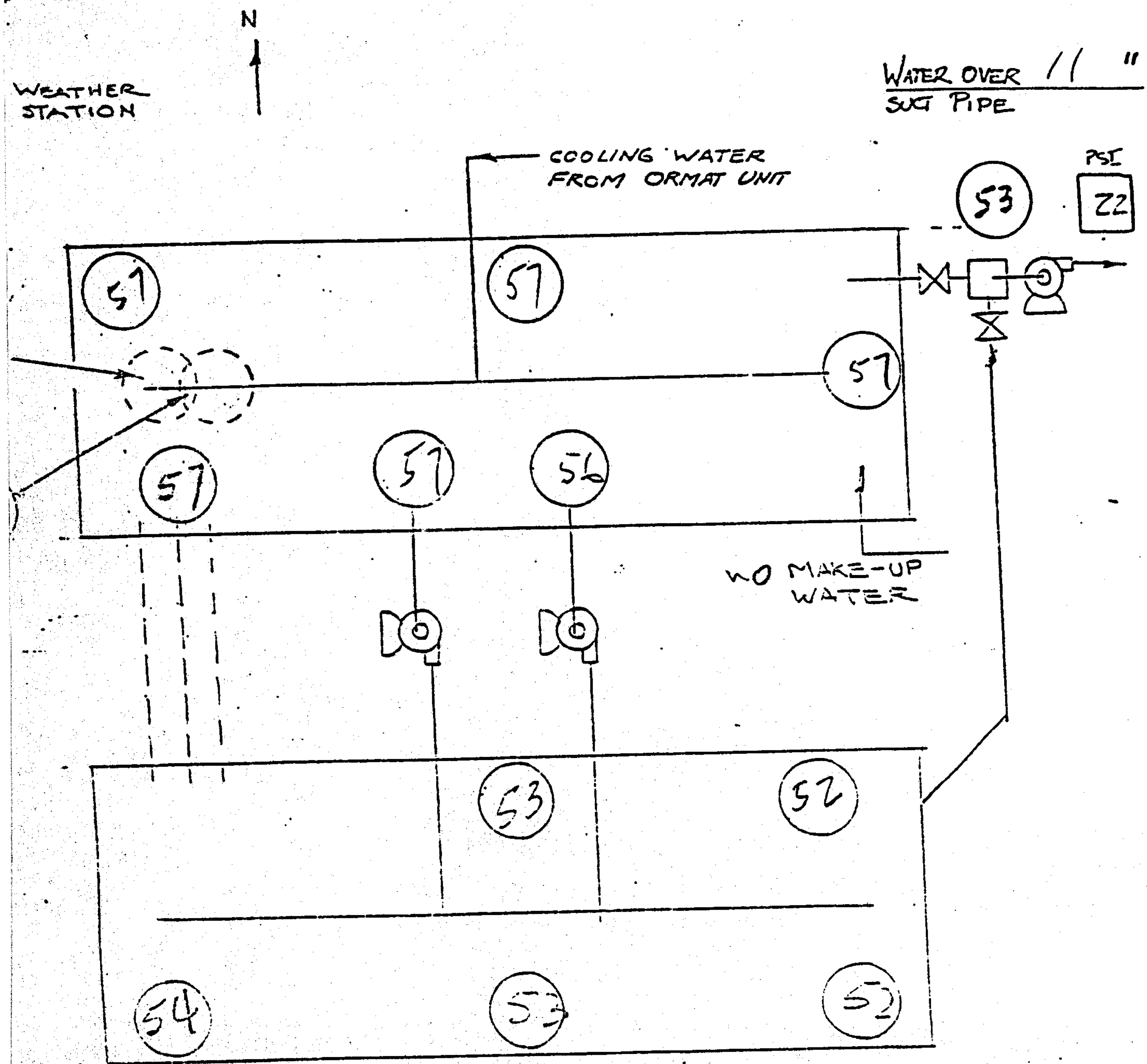
AMB. TEMP 28



DATE: 10-16-85

TIME: 6.40

AMB. TEMP 28



DATE: 10-16-55

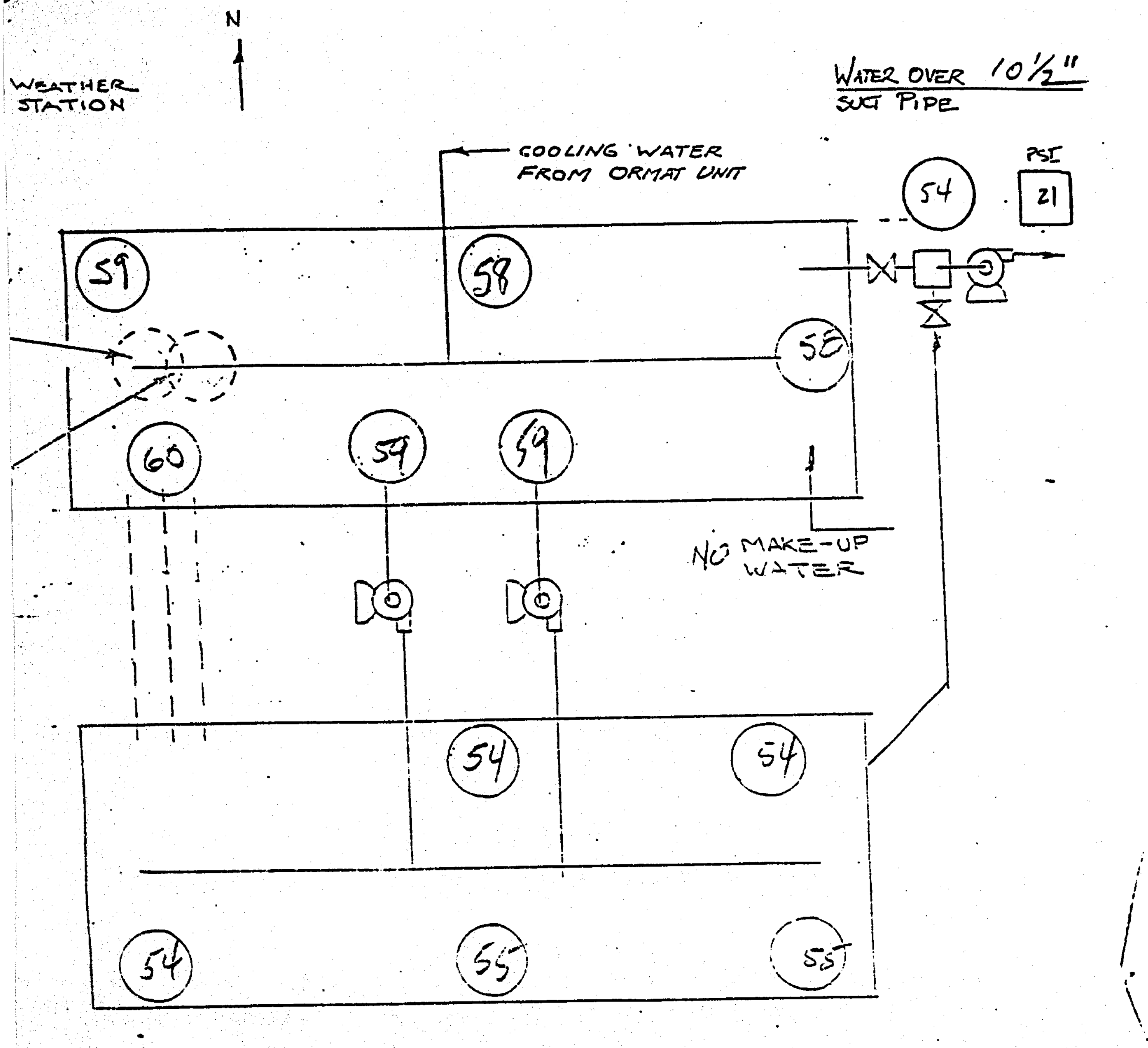
TIME: 0900

AMB. TEMP

S.C.O

LOS 52

75 65



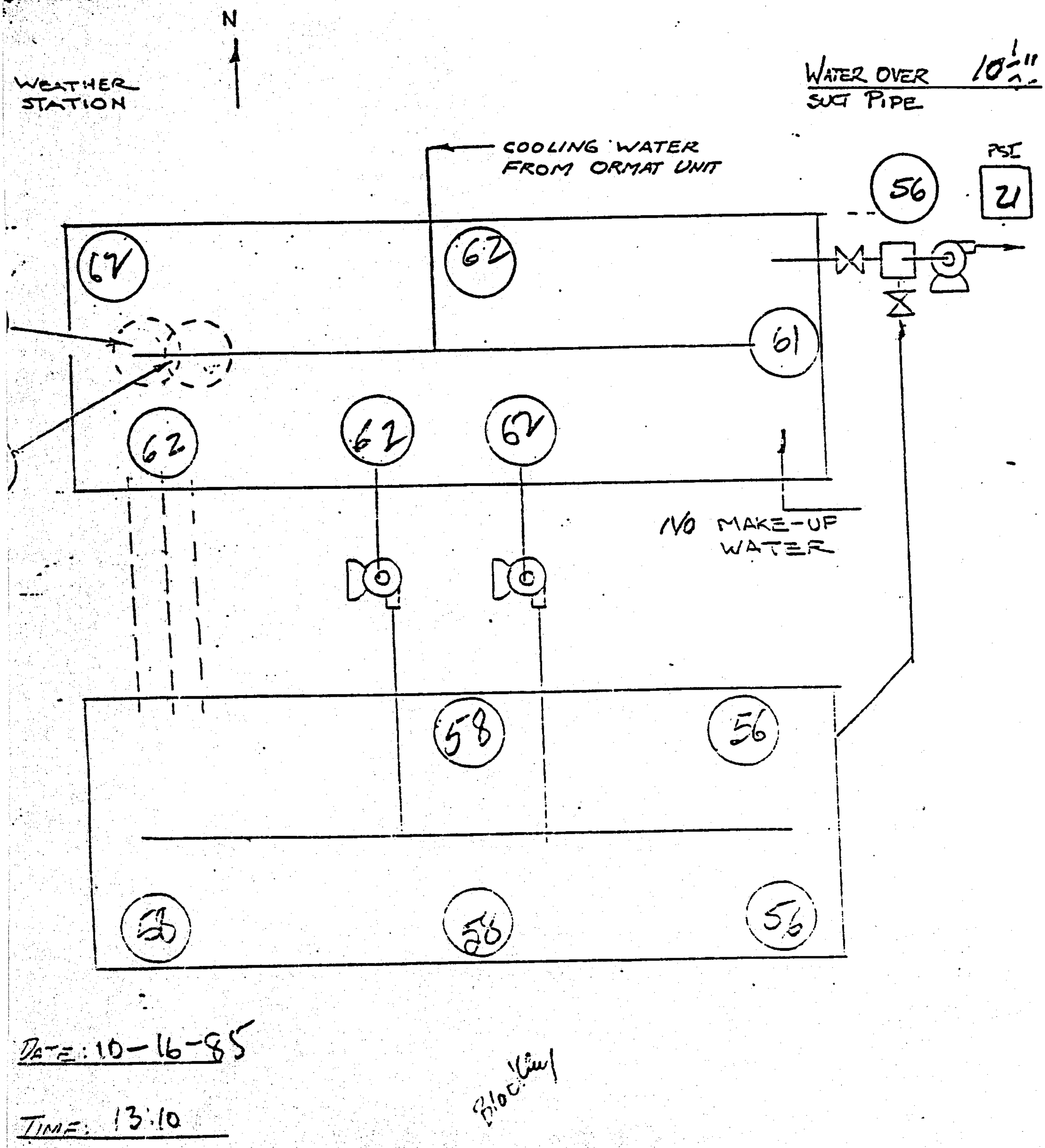
DATE. 10-16-85

TIME: 11:30

AMB. TEMP 55

Blocking

SILO
WB 50
DB 58



Date: 10-16-85

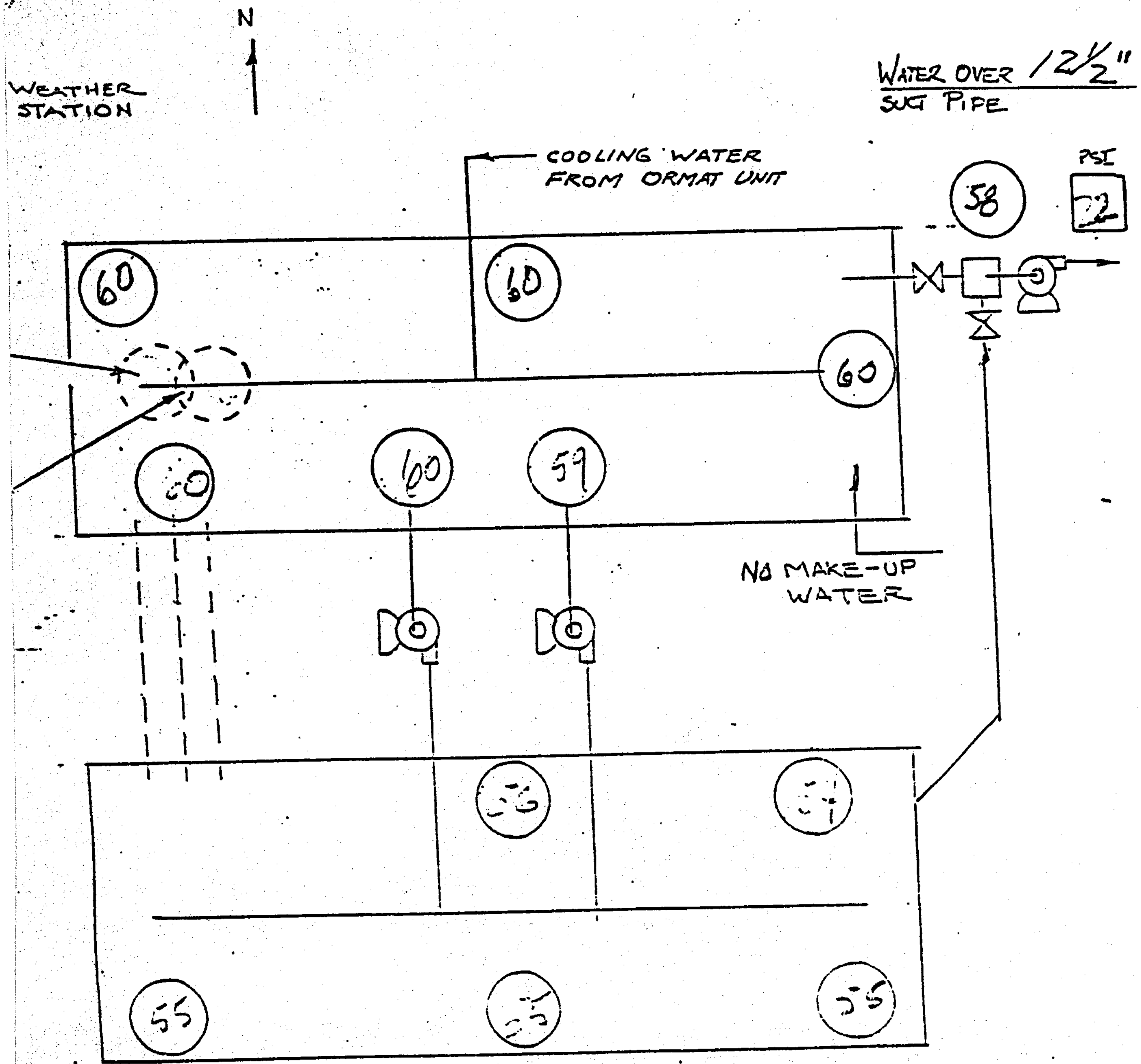
Time: 13:10

Amb. Temp = 64

Silo

WB 54

DB 68



DATE: 10-15-85

TIME: 23:00 - 23:45

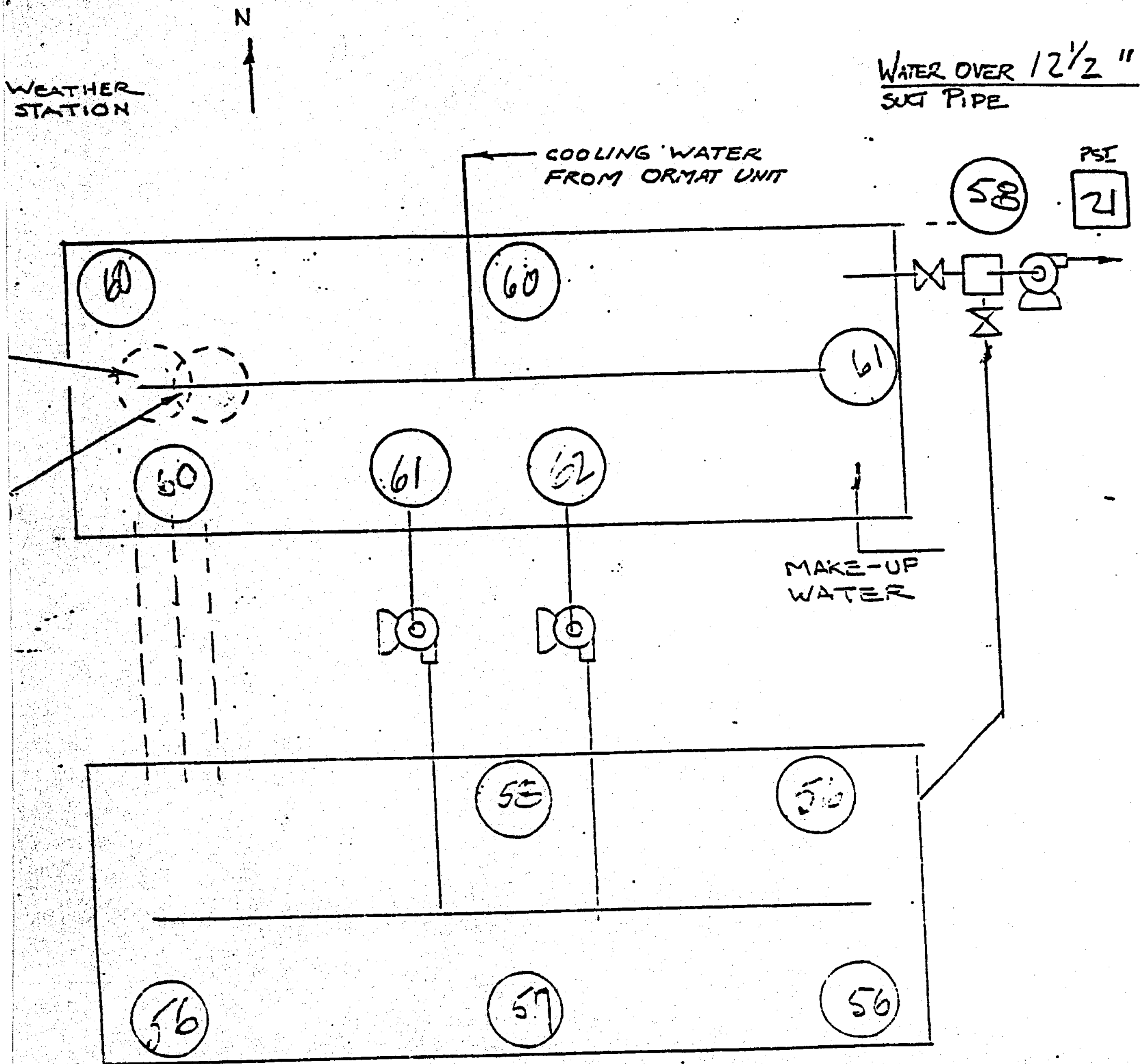
AMB. TEMP ———

Brockley

Silo

WB 34

DB 37



DATE: 10-15-85

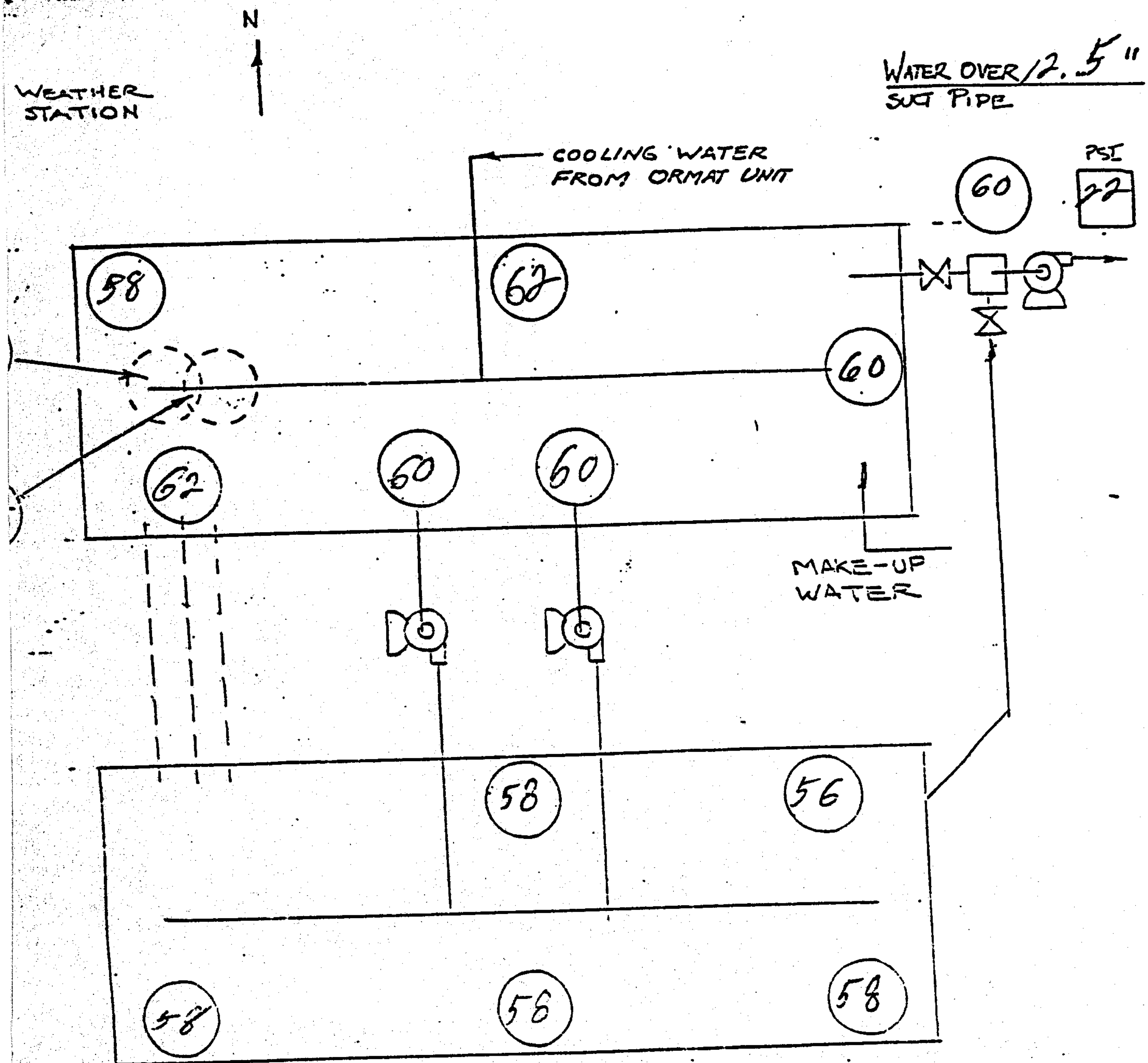
TIME: 21:15 – 21:40

AMB. TEMP 44

SILO

WB 39

DB 43°F

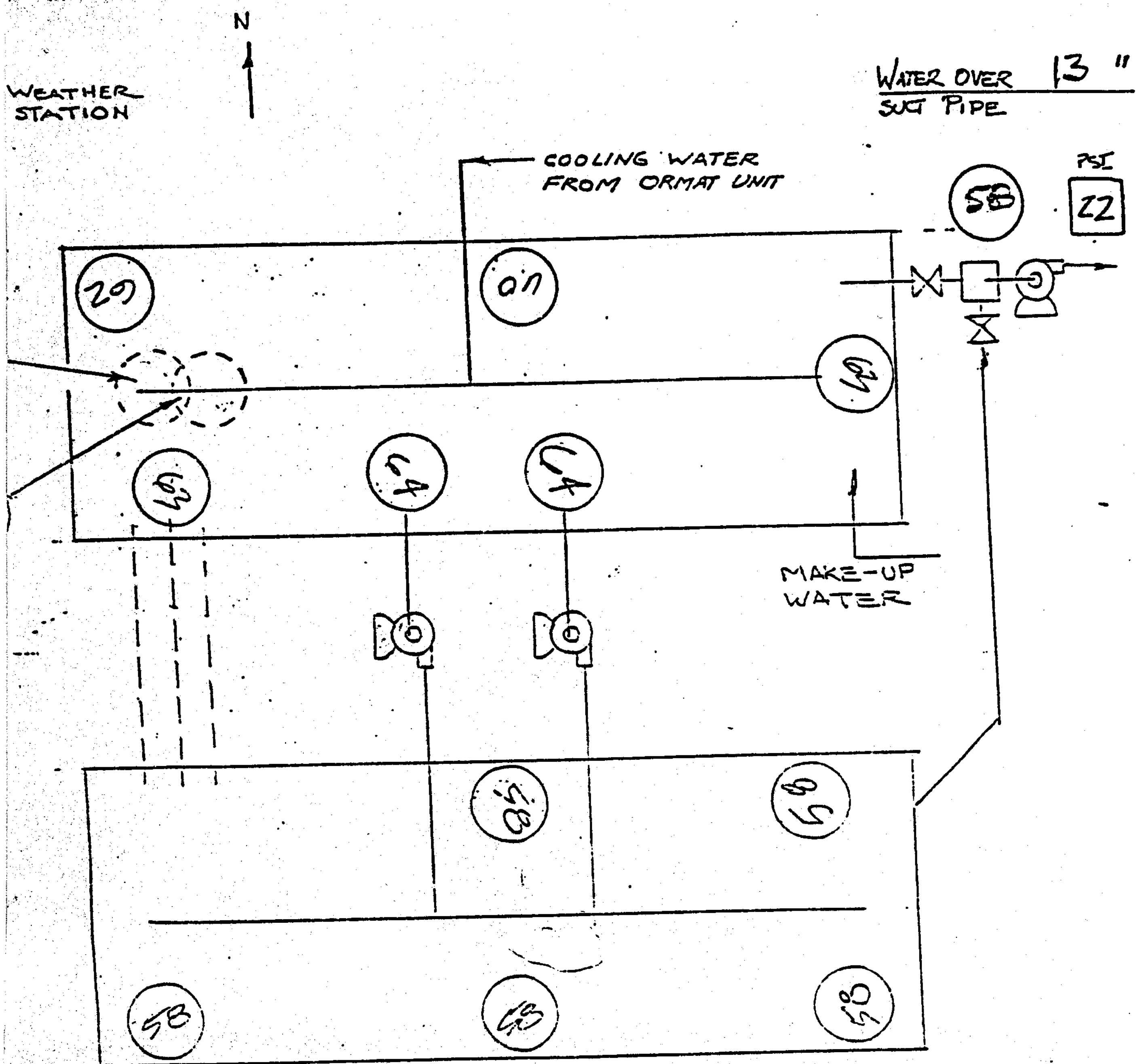


DATE: 10/15/85

TIME: 7:15 PM

AMB. TEMP 53 DB
44 WB

by Culver
Dumble



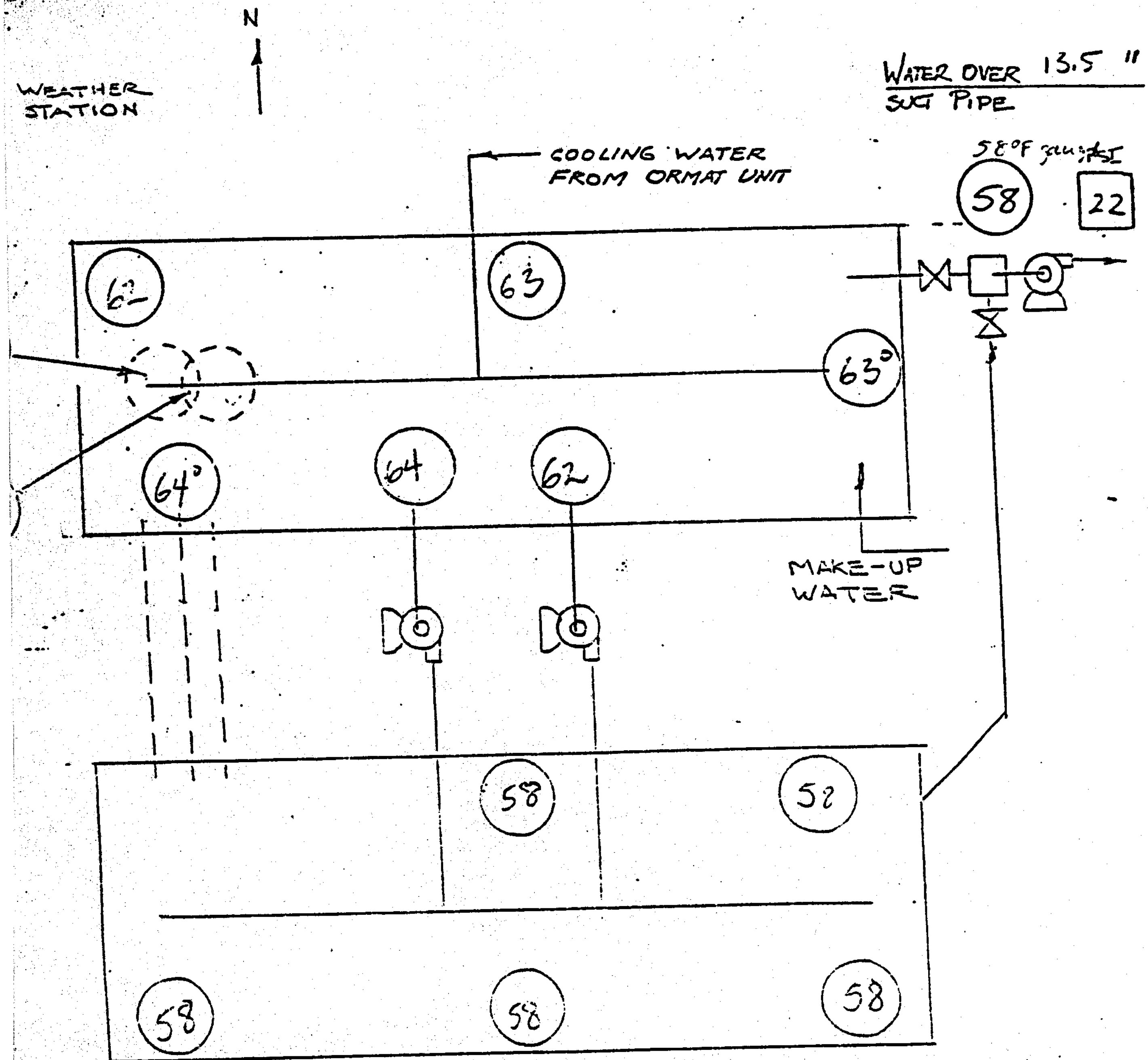
GRAIN SILO
AMB TEMP 66°F
WET BULB 52°F

DATE: 10-15-85

TIME: 17:00

AMB. TEMP 62 @ 17:20

Blockley

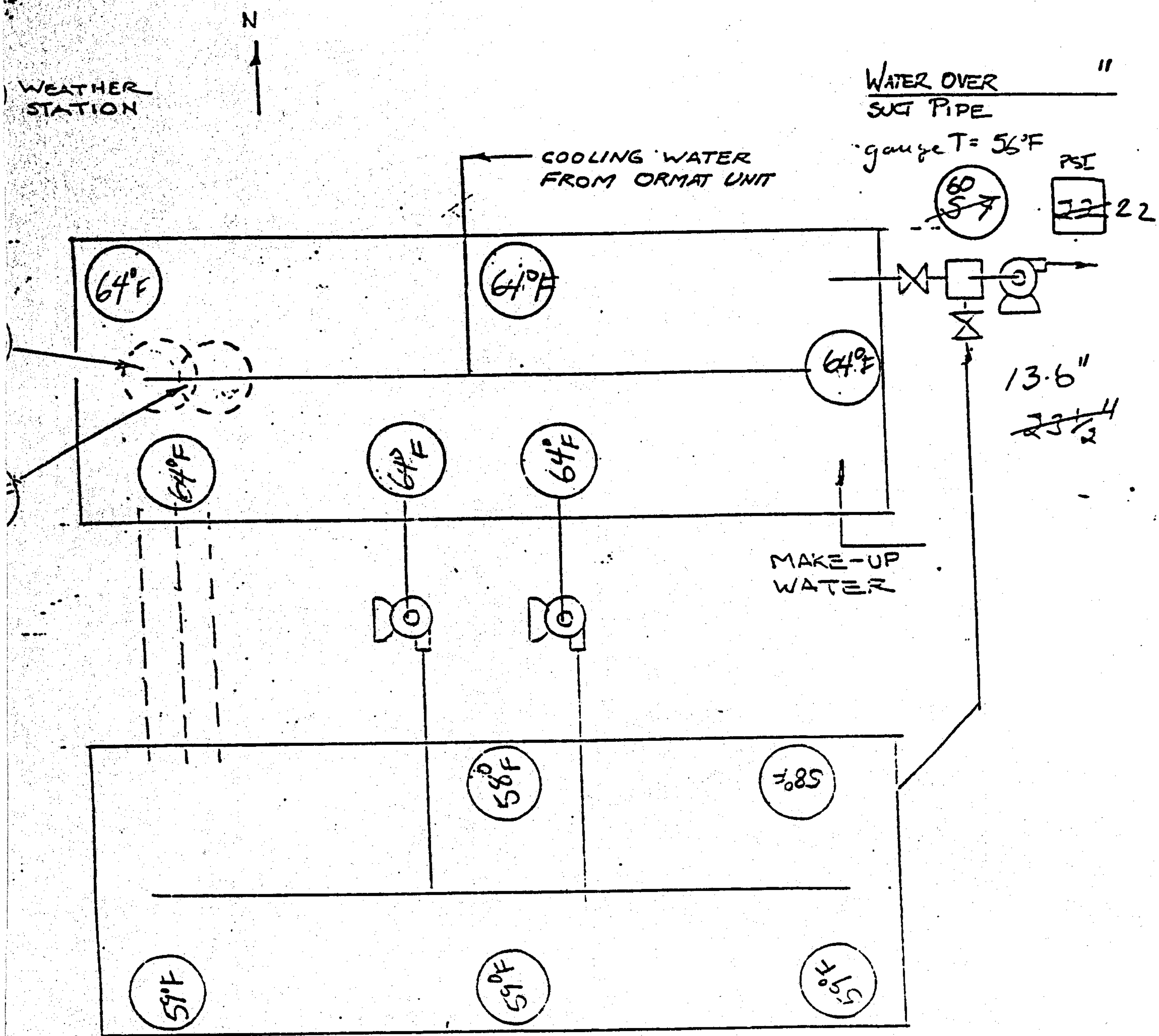


DATE: 10-15-85

TIME: 3:25

AMB. TEMP 63°F

Data taken by White & Junius



12.2?

4 = 15.3?°C = 59°F

5 = 22.68% H

7 = 158°

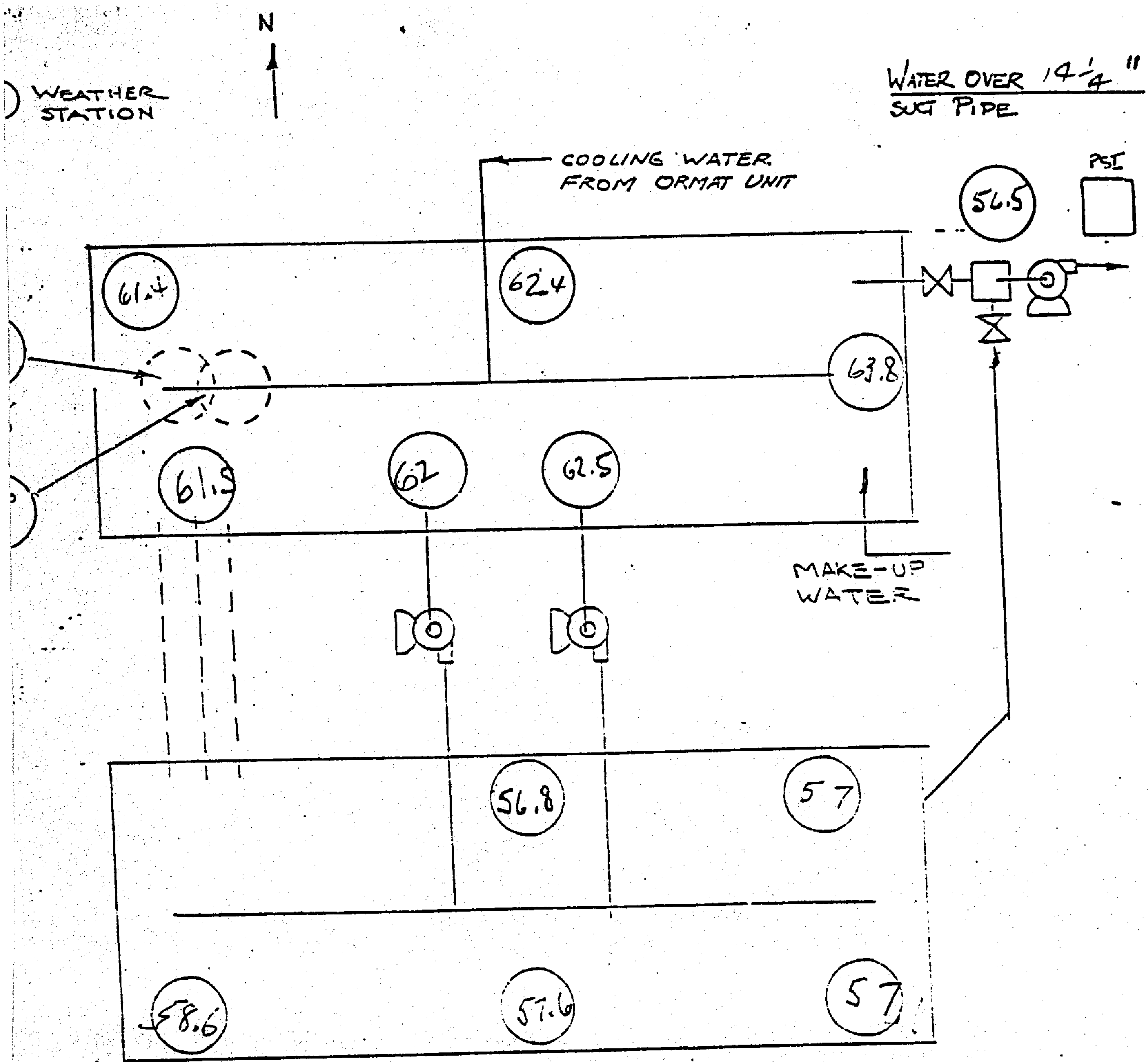
8 = 5.3 MPH

DATE: 10-15-85

TIME: 1:15 pm

AMB. TEMP 59.5°F

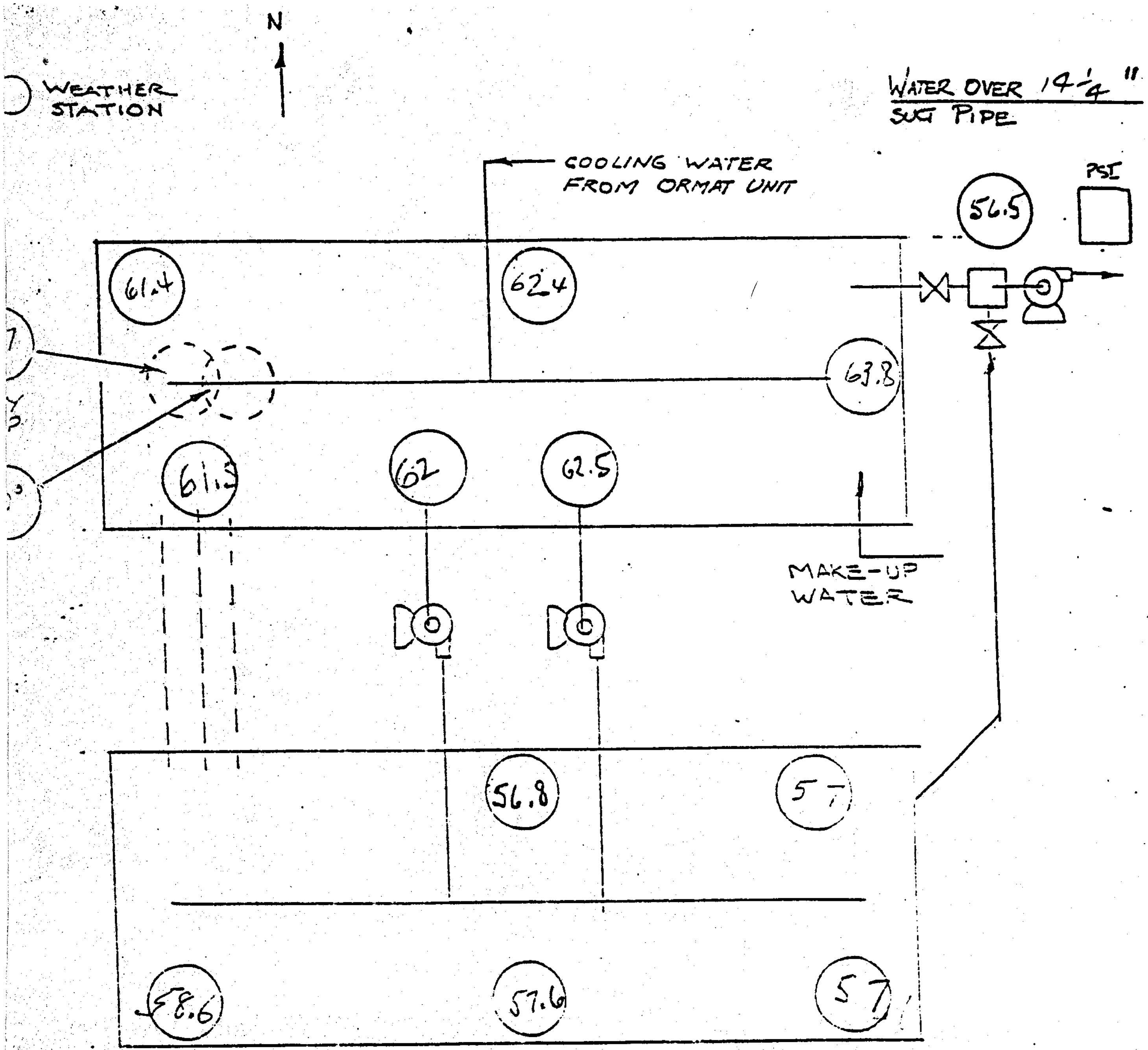
data taken by White & Junius



DATE: 3-6-86

TIME: 07:30

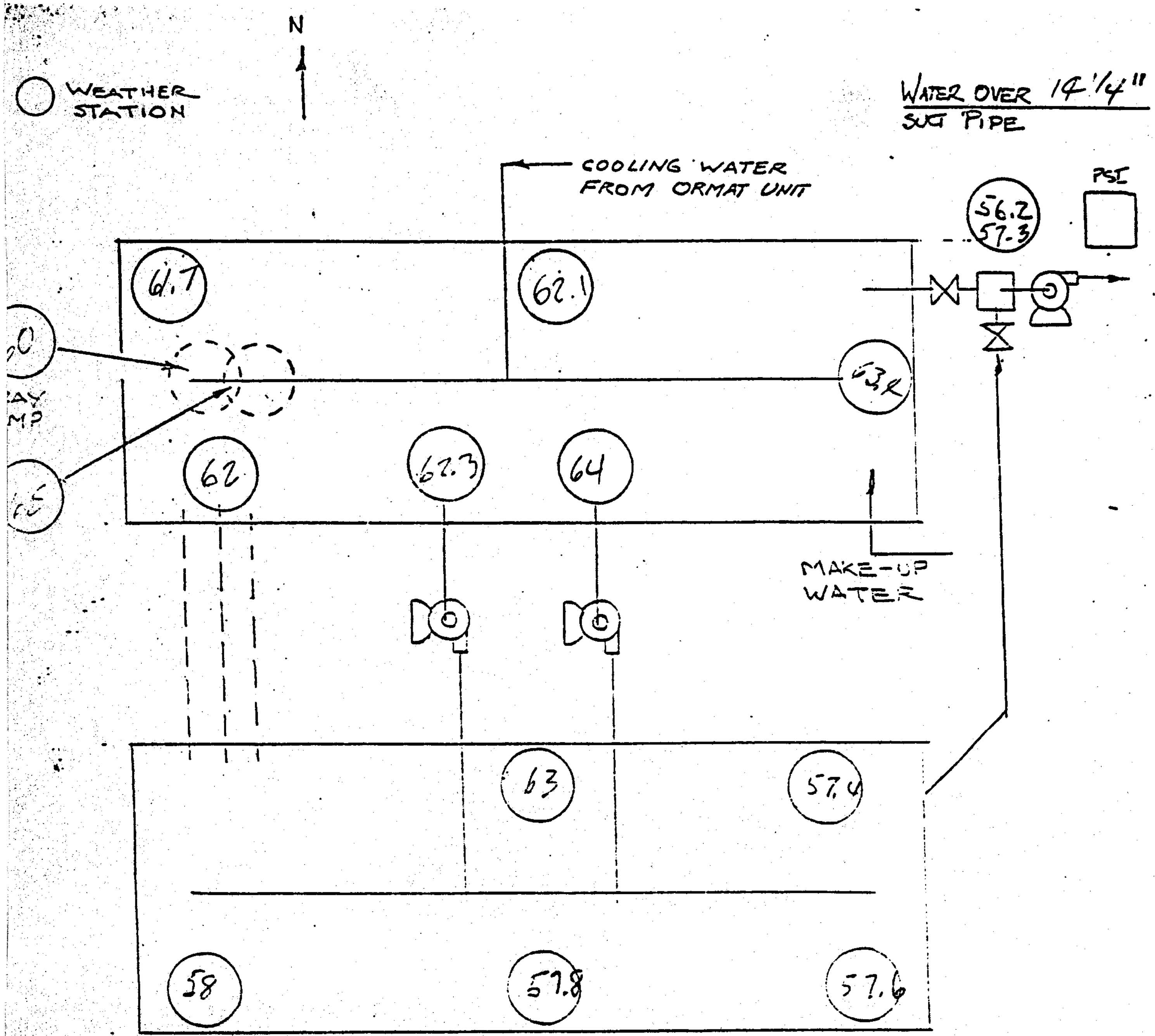
AMB. TEMP= 50°F



DATE: 3-6-86

TIME: 07:30

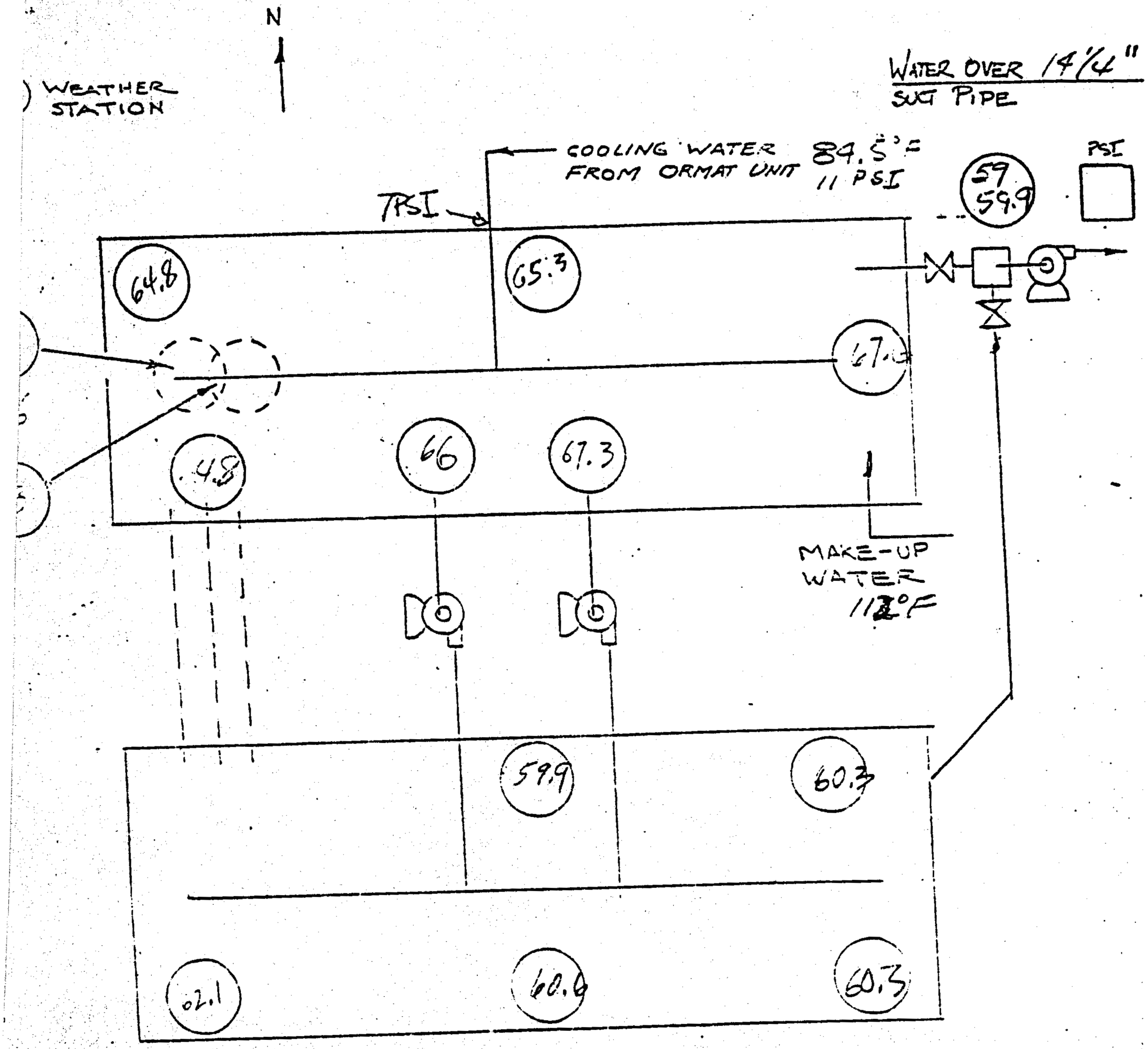
AMB. TEMP 50°F



DATE: 3-6-86

TIME: 09:00

AMB. TEMP 54
WB " 48

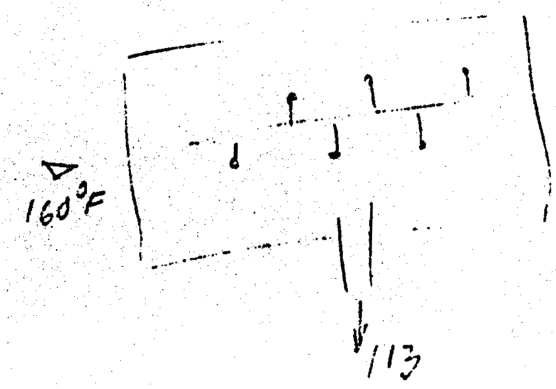


DATE: 3-6-86

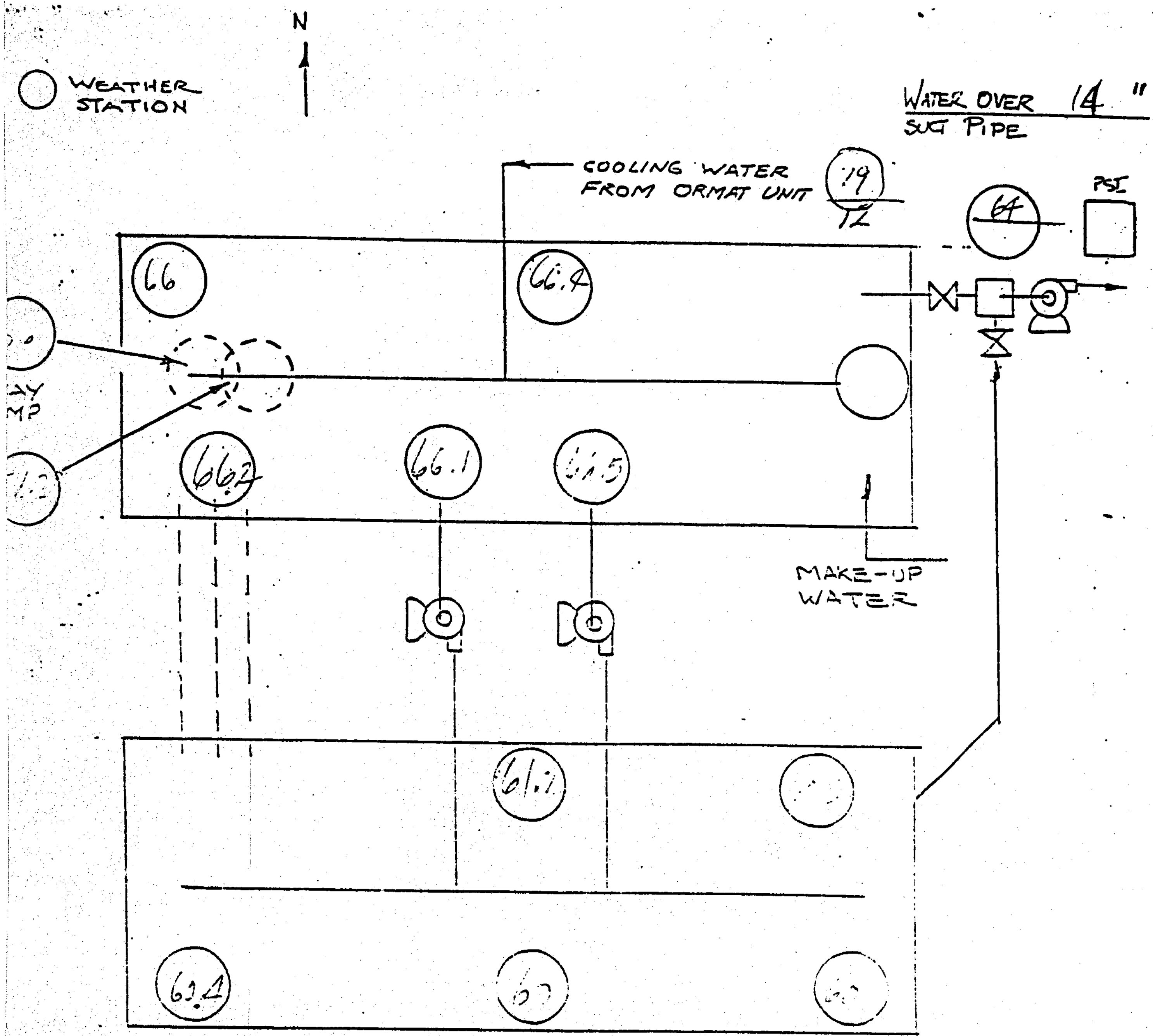
TIME: 11:00

AMB. TEMP 62

WB Temp 54



- Yerington
Wind Generator

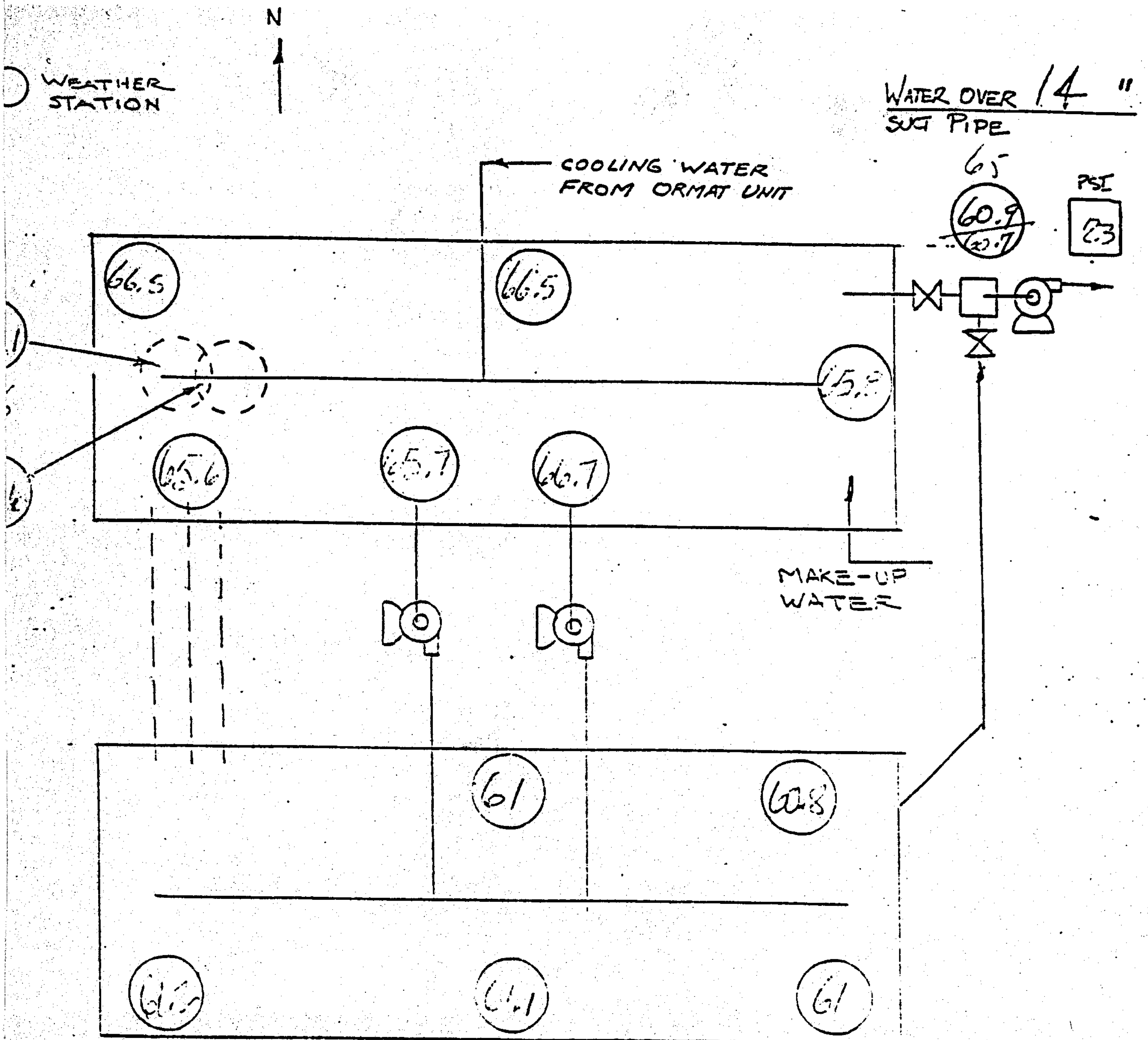


DATE: 3/6 8[illegible]

TIME: 13:00

AMB. TEMP 70

[illegible] — 56

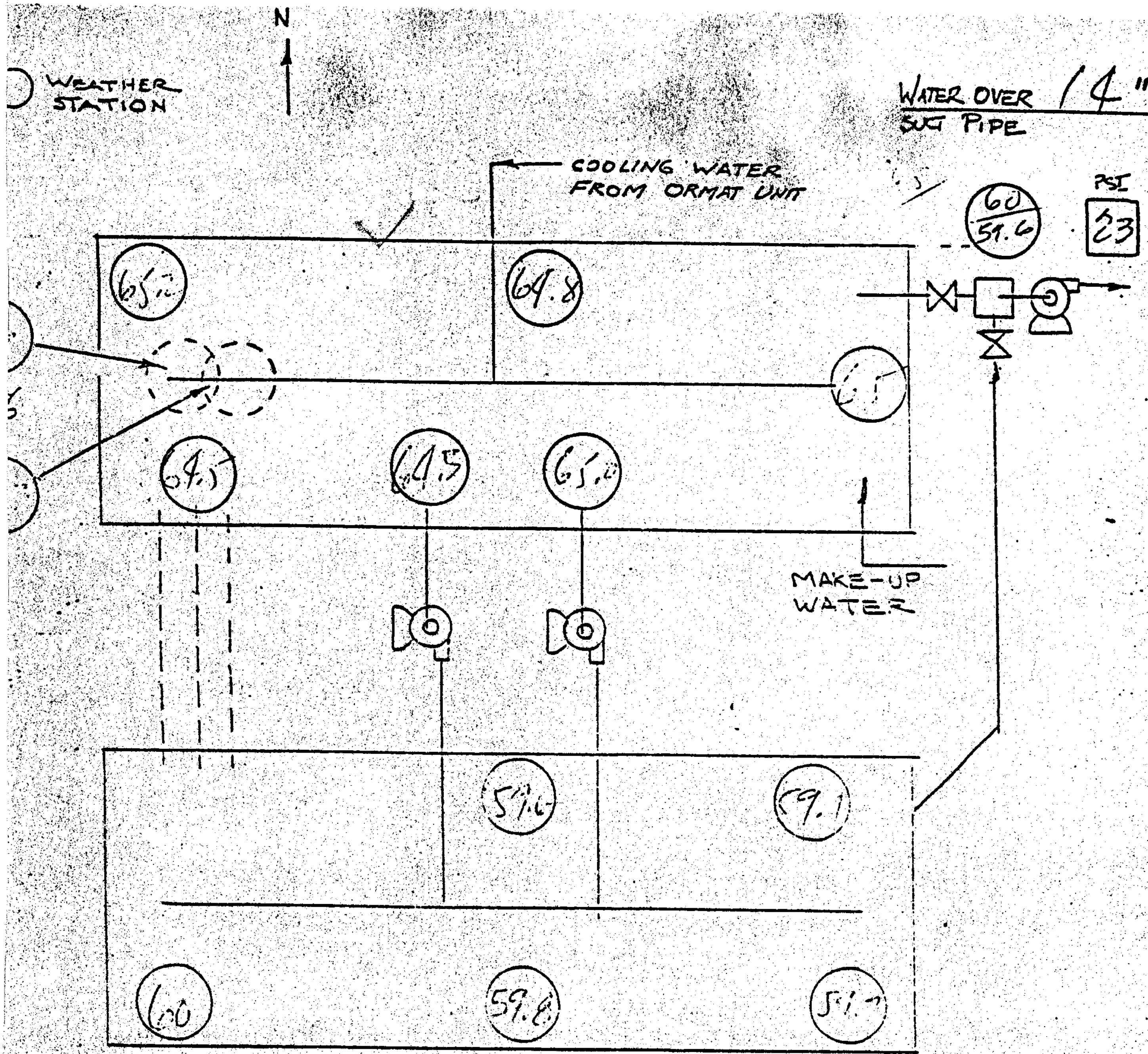


DATE: 3/6/86

TIME: 1500

AMB. TEMP - 68

WB - 54

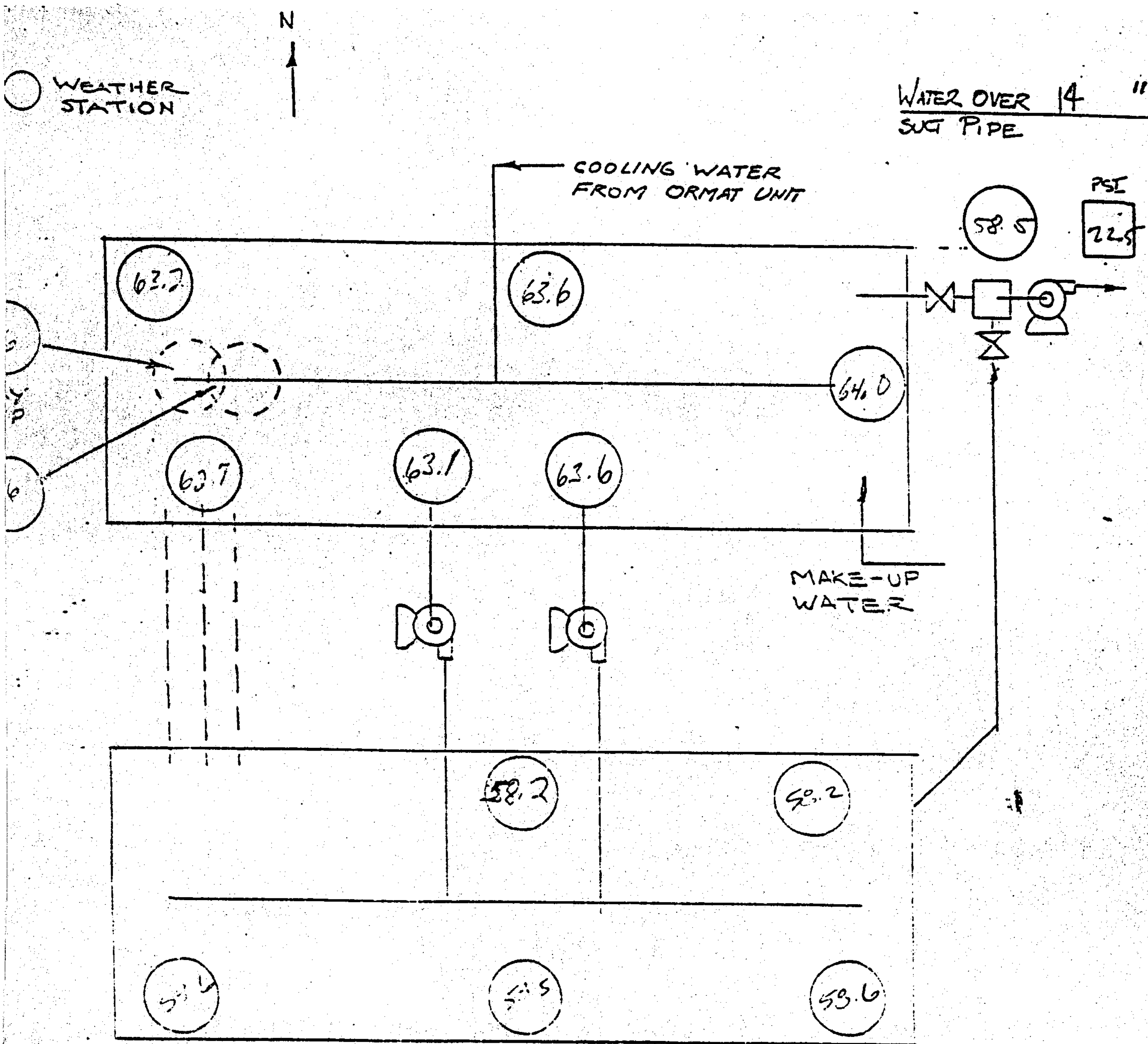


DATE: 3/6/86

TIME: 1100

AMB. TEMP DB 64

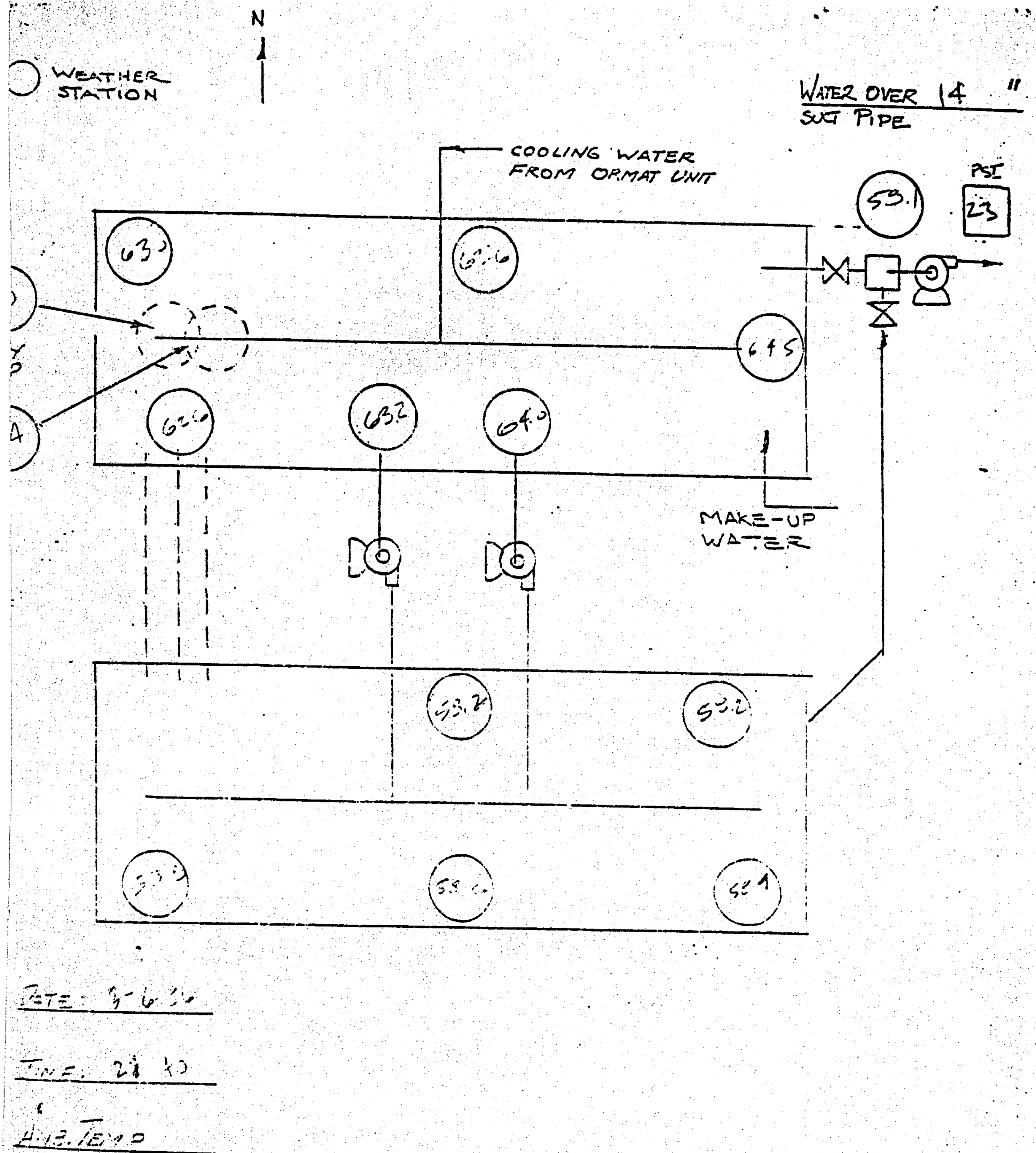
WB 51

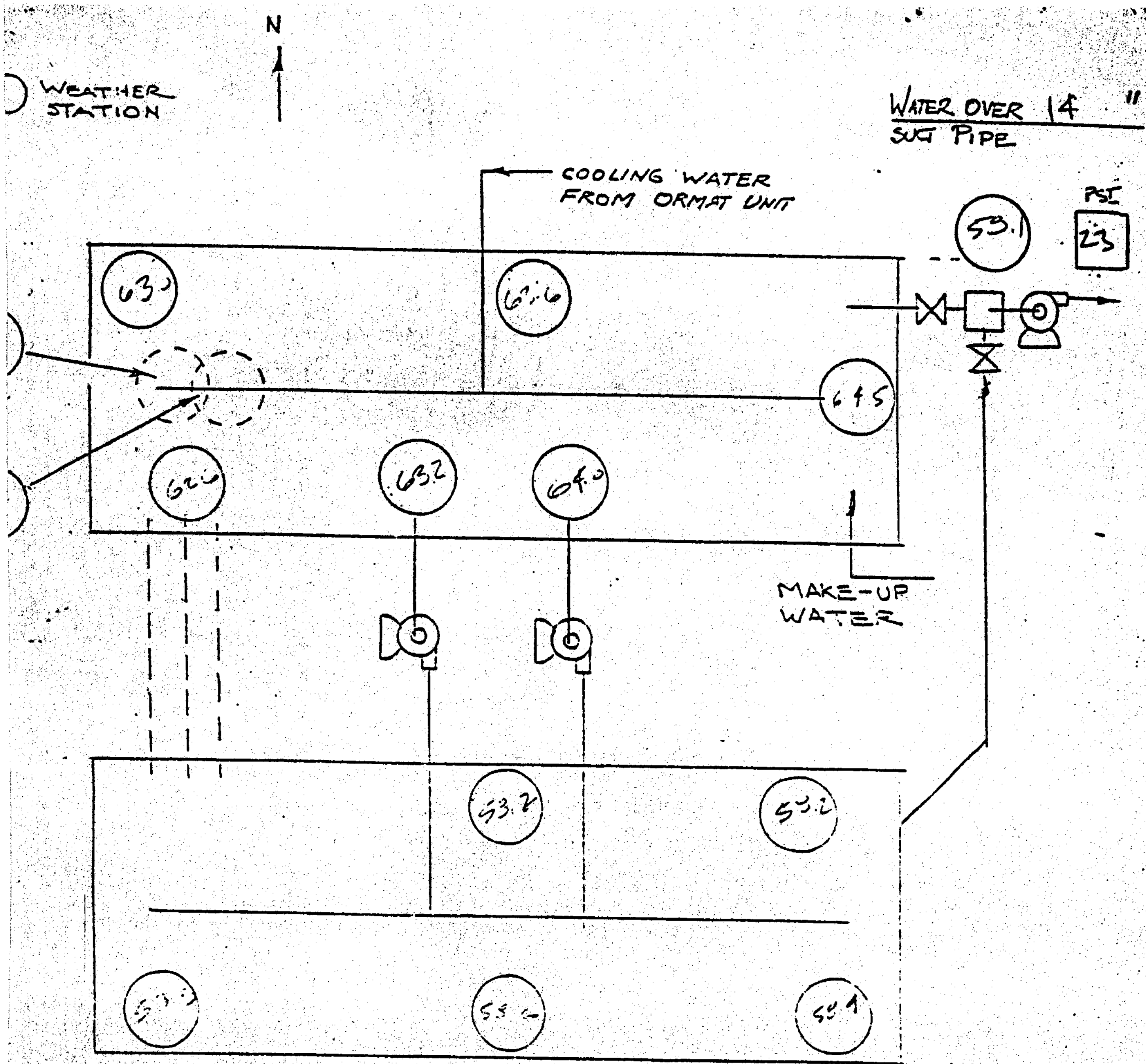


DATE: 3-6-86

TIME: 19 40

AMB. TEMP. WB - 47 DB - 57

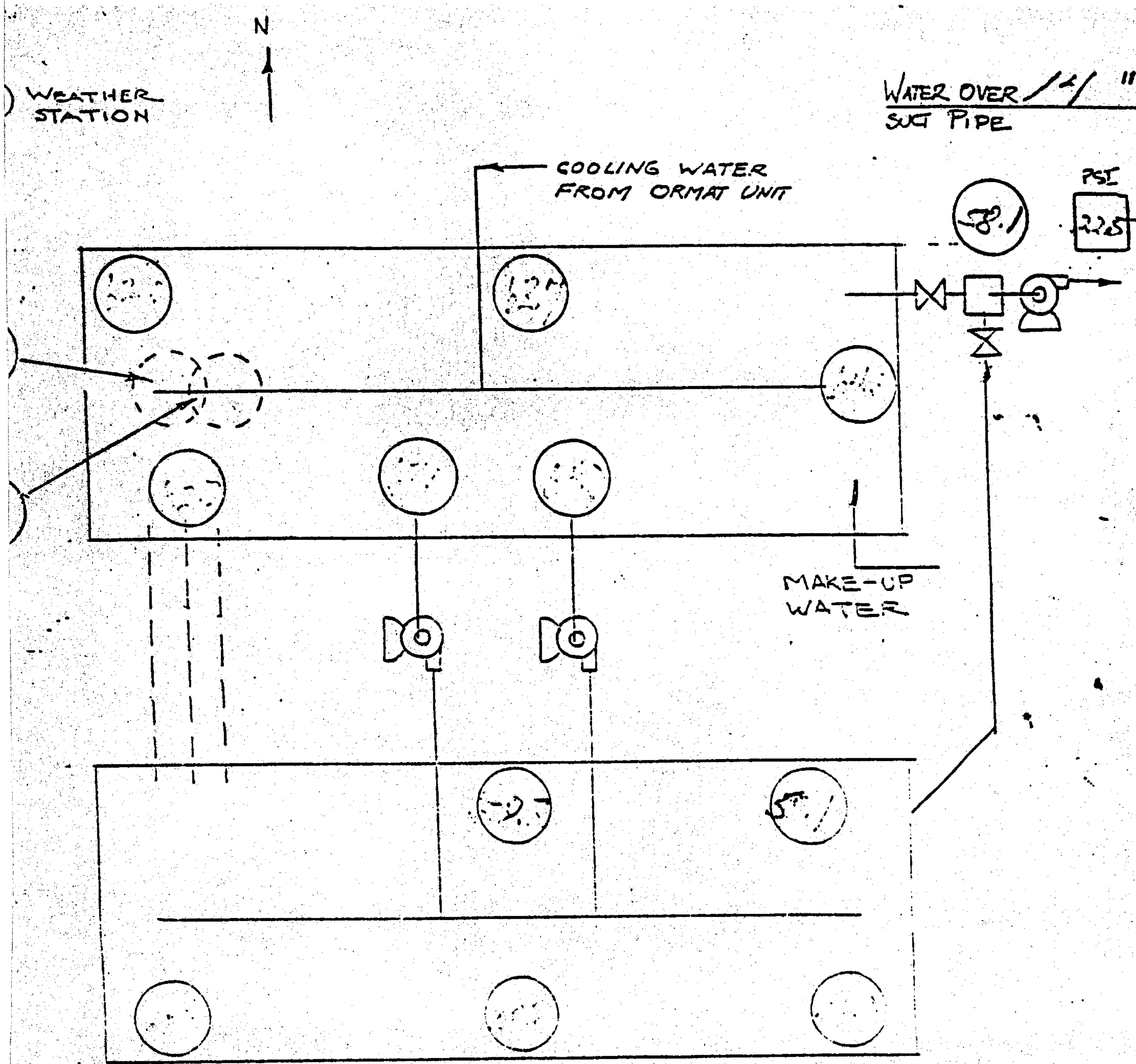

WEATHER STATION
N
WATER OVER 14 "
SUCT PIPE
COOLING WATER FROM ORMAT UNIT
PSI
23
53.1
645
632
640
MAKE-UP WATER
53.2



Date: 3-6-96

Time: 21 40

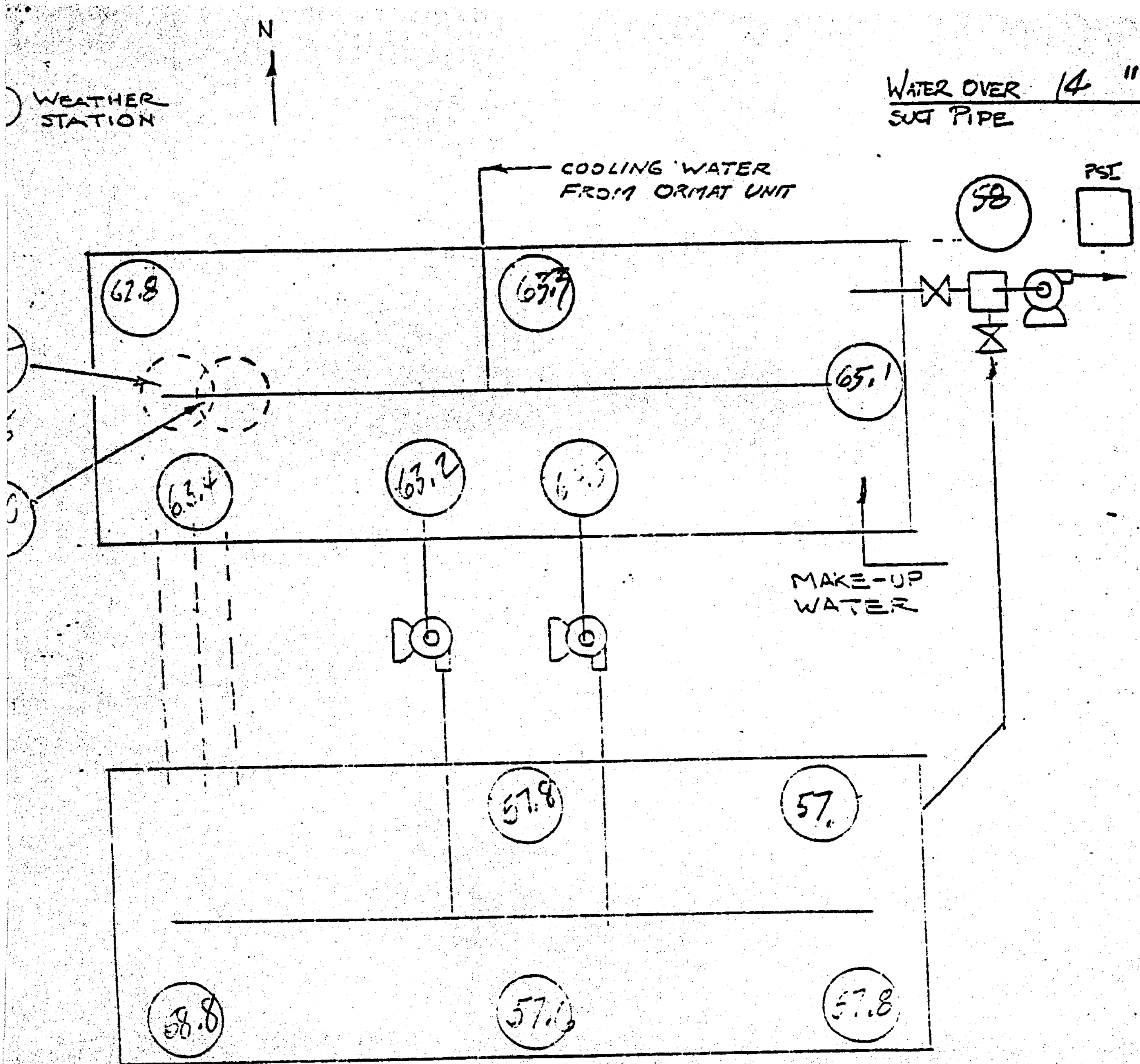
Amb. Temp



DATE: 3-4-80

TIME: 22:

AMB. TEMP

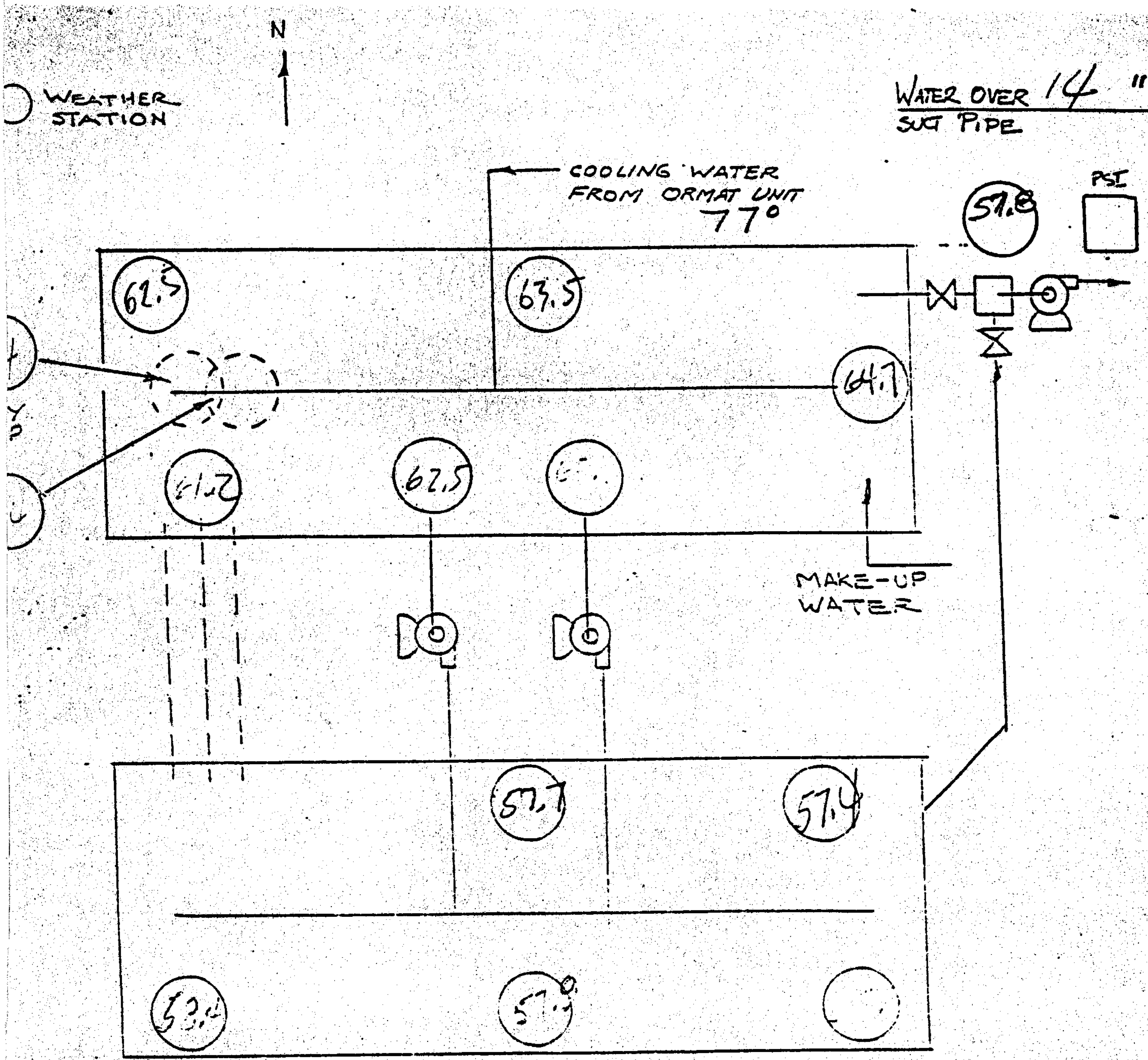


DATE: 3-7-86

TIME: 01:00

AMB. TEMP 48

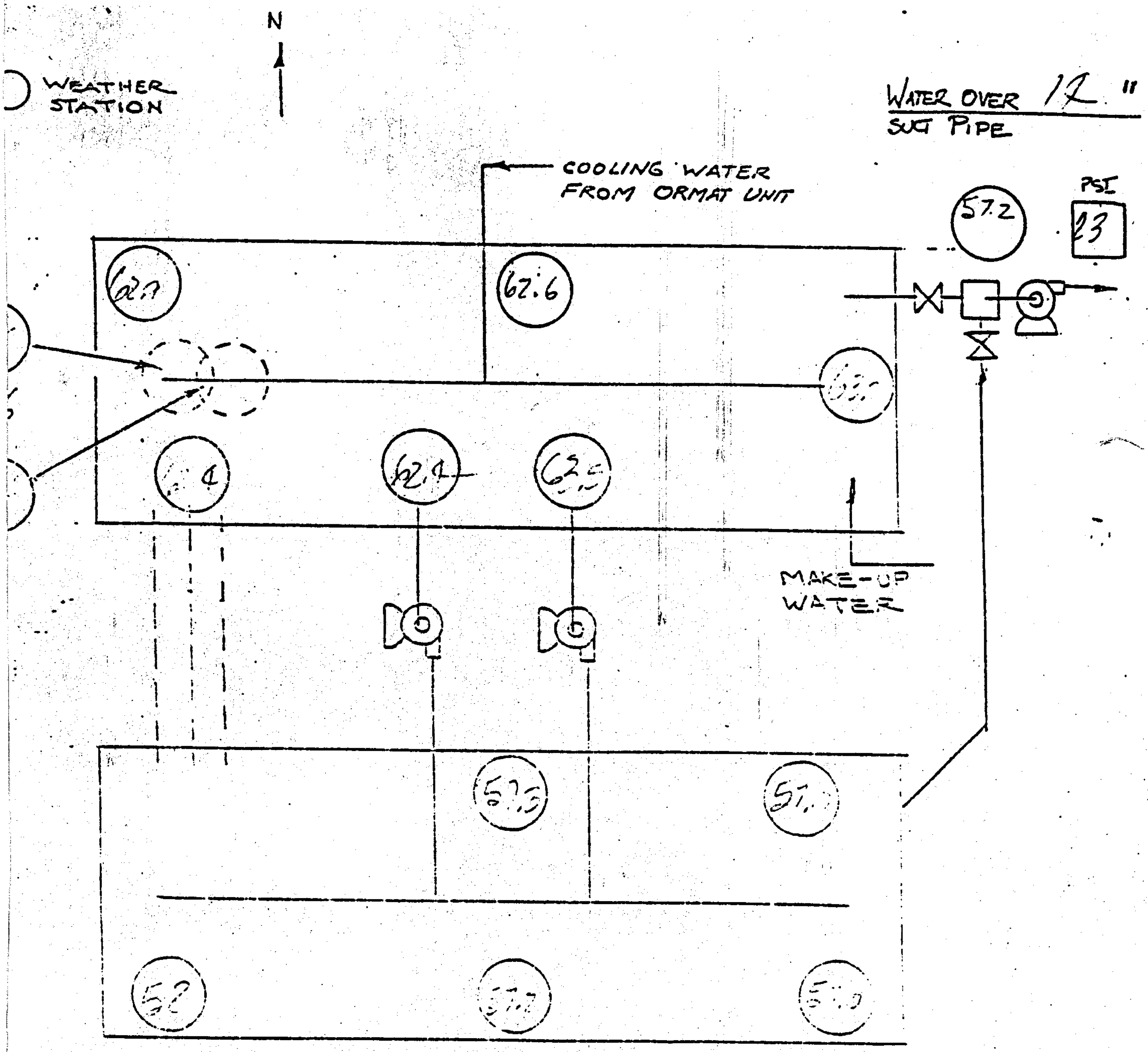
WB 44



DATE: 3-7-86

TIME: 23:00

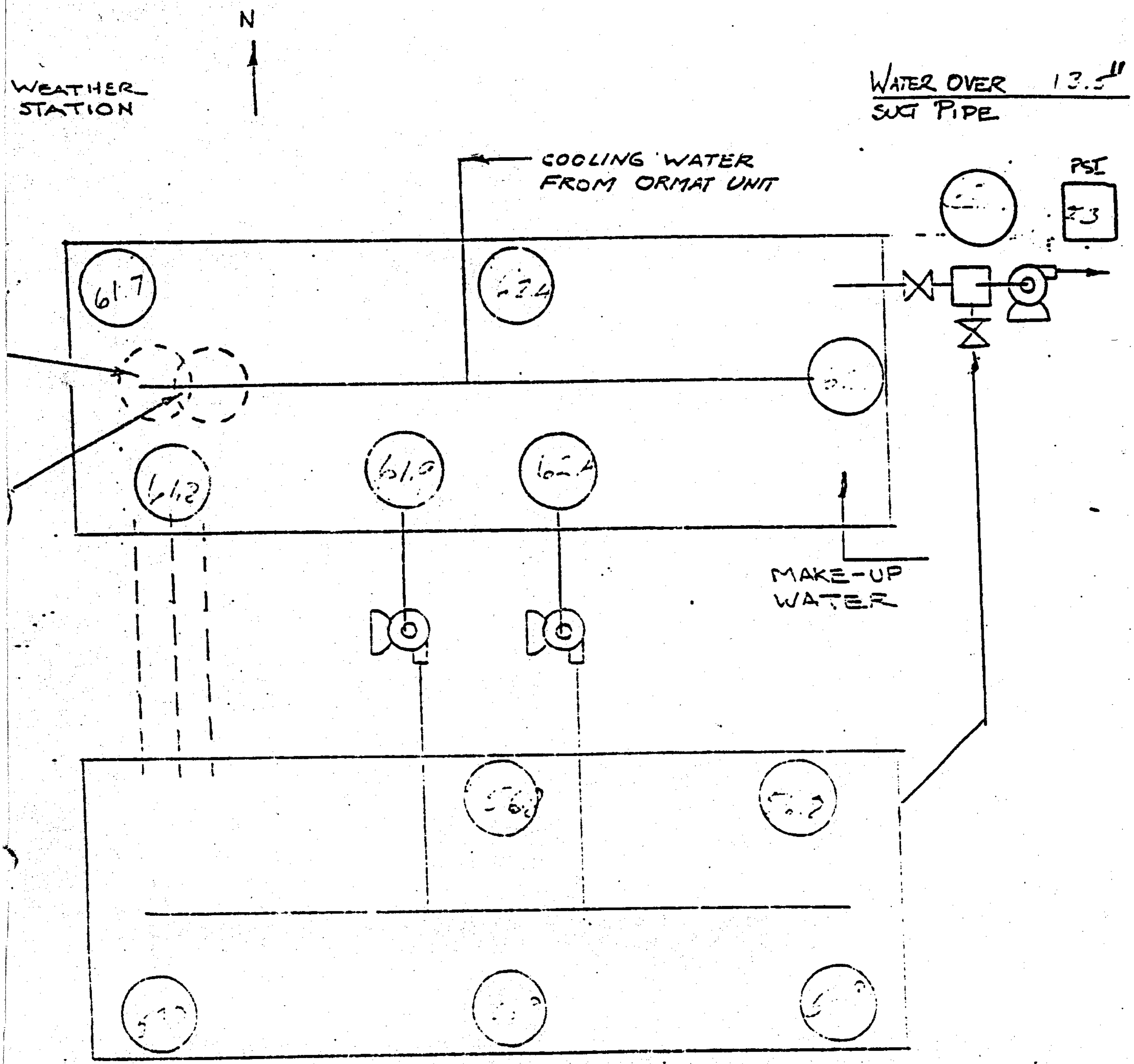
AMB. TEMP = 48
W/B 44



DATE: 3-4-86

TIME: 05:00

AMB. TEMP = DB 53
WB 45



DATE:

TIME:

AMB. TEMP

APPENDIX G

Parasitic Loads Data

GEOTHERMAL WELL/PUMP

Well

Diameter	12 inch
Depth	350 feet
Static Water Level	artesian - shut in pressure
Bubbler Tube	283 feet

Pump

Type/Size	Centrilift Hughes submersible. Series 875, Type 1B-700
Capacity	700 gpm @ 353 ft TDH
Horsepower (Nameplate)	100
Voltage	1140 volts
Amperes	55 amps
Submergence	285 feet, 309 (2/86)

AUXILIARY LOADS

Freon Circulating Pump

Type Pump/Size	5 stage horizontal
Capacity	GPM
Horsepower (Nameplate)	60
Voltage	480 volts
Amperage	77 amps

Expander Oil Pump

Type Pump/Size	
Capacity	
Horsepower (Nameplate)	1
Voltage	400 (nameplate)
Amperage	1.95 (nameplate)

Instrument Air Compressor

Type/Size	3 cyl single stage
Capacity	
Horsepower (Nameplate)	3
Voltage	440
Amperage	3.9

Cooling

Type/Size	PACO 29-10151-370500
Capacity	3000 gpm
Horsepower (Nameplate)	50
Voltage	460
Amperage	87 amp

Spray Pond Transfer Pump
E5

Type/Size	Aurora Mod 3x4 15563 type 344 size 6x6x12
Capacity	1500 gpm @ 40' TDH
Horsepower	10
Voltage	460
Amps	13
Running Time	continuous

Auxiliary Loads cont'd

Spray Pond Transfer Pump
E6

Type/Size	Aurora Mod 3x4 15563 type 344 size 6x6x12
Capacity	1500 gpm @ 40' TDH
Horsepower	10
Voltage	460
Amps	13
Running Time	continuous

GEOTHERMAL WELL/PUMP

Well

Diameter	12 inch
Depth	350 feet
Static Water Level	artesian - shut in pressure
Bubbler Tube	283 feet

Pump

Type/Size	Centrilift Hughes submersible. Series 875, Type 1B-700
Capacity	700 gpm @ 353 ft TDH
Horsepower (Nameplate)	100
Voltage	1140 volts
Amperes	55 amps
Submergence	285 feet, 309 (2/86)

AUXILIARY LOADS

Freon Circulating Pump

Type Pump/Size	5 stage horizontal
Capacity	GPM
Horsepower (Nameplate)	60
Voltage	480 volts
Amperage	77 amps

Expander Oil Pump

Type Pump/Size	
Capacity	
Horsepower (Nameplate)	1
Voltage	400 (nameplate)
Amperage	1.95 (nameplate)

Instrument Air Compressor

Type/Size	3 cyl single stage
Capacity	
Horsepower (Nameplate)	3
Voltage	440
Amperage	3.9

Cooling

Type/Size	PACO 29-10151-370500
Capacity	3000 gpm
Horsepower (Nameplate)	50
Voltage	460
Amperage	87 amp

Spray Pond Transfer Pump
E5

Type/Size	Aurora Mod 3x4 15563 type 344 size 6x6x12
Capacity	1500 gpm @ 40' TDH
Horsepower	10
Voltage	460
Amps	13
Running Time	continuous

Auxiliary Loads cont'd

Spray Pond Transfer Pump
E6

Type/Size	Aurora Mod 3x4 15563 type 344 size 6x6x12
Capacity	1500 gpm @ 40' TDH
Horsepower	10
Voltage	460
Amps	13
Running Time	continuous

APPENDIX H

Comments by Ormat