Fermi National Accelerator Laboratory

TM-1530

Technical Manual for Calculating Cooling Pond Performance

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July 1, 1988

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

Technical Manual For Calculating Cooling Pond Performance

S. F. Krstulovich

Construction Engineering Services

July 1, 1988

INDEX

SECTION I	Introduction
SECTION II	Cooling Pond Performance Report
SECTION III	Cooling Pond Performance Criteria Graphs
SECTION IV	Cooling Pond Performance Temperature Extrapolation Formula and Mathematical Models
SECTION V	Cascade Cooling Ponds Performance Formulas
SECTION VI	Main Ring Ponds Performance Calculations
SECTION VII	Main Ring Ponds Thermal Analysis Drawing

Introduction

This manual is produced in response to a growing number of requests for a technical aid to explain methods for simulating cooling pond performance. As such, it is a compilation of reports, charts and graphs developed through the years for use in analyzing situations.

Section II: Contains a report summarizing the factors affecting cooling pond performance and lists statistical parameters used in developing performance simulations.

Section III: Contains the graphs of simulated cooling pond performance on an hourly basis for various combinations of criteria (wind, solar, depth, air temperature and humidity) developed from the report in Section II.

Section IV: Contains correspondence describing how to develop further data from the graphs in Section III, as well as mathematical models for the system of performance calculation.

Section V: Contains the formulas used to simulate cooling pond performances in a cascade arrangement, such as the Fermilab Main Ring ponds.

Section VI: Contains the calculations currently in use to evaluate the Main Ring pond performance based on current flows and Watts loadings.

Section VII: Contains the overall site drawing of the Main Ring cooling ponds with thermal analysis and physical data.

II

Cooling Pond Performance Report

Fermilab

September 12, 1985

Memo to: M. Palmer

From: S. Krstulovich Construction Engineering

Subject: Cooling Pond Performance

Enclosed are copies of all of the calculated cooling pond performance curves displayed at the Main Ring Pond Meeting held on Tuesday, September 10, plus two (2) new series of curves (the E and F Series) defining pond stability during various semi-daily wind changes. Due to the very brief time allowed for calculating the thousands of points necessary, the curves are a little rough but certainly more than adequate for this type of evaluation.

To summarize pond performance in terms of depth, it seems in general that thermal stability begins to occur only at depths of 3′ and greater and that the benefits of increasing pond depth begins to diminish rapidly beyond the 4′-6″ depth. The basic shape of the thermal performance curves is determined by environmental factors, while uniform loading of watts per square foot only elevates the basic curve. Note that pond temperatures plotted are the logarithmic mean and can be extrapolated for any desired Δt. Increasing pond depth does not do much for reducing the average daily pond temperature for any condition, but rather serves only to minimize cycling extremes.

The major factors affecting pond performance (outside of watts per square foot loading) are listed here in descending order of importance.

1. Wind Velocity: This affects pond cooling more than any other single factor. The A thru C Series of curves are calculated for a reasonable daily average wind of 5 mph. The D Series curves represents the extreme case of absolutely no wind for an entire day (a very unlikely possibility due to uneven solar surface heating) and should be viewed as a limit rather than a true condition because of the importance laid on thermal stability (due to magnet piping failure at stress intensification points). In view of the real possibility of daily wind velocity cycling, it was deemed worthwhile to generate the new E and F Series curves defining the two extremes of wind variation effects. The E Series curves depict the

rather common phenomenon of breezy days and still nights. The curves illustrate that this tends to enhance thermal stability (with the exception of ponds in the 1'-6" depth range which tends to overreact) but at the expense of creating slightly higher average temperatures than during steady daily breezes. The F Series curves depict the less common phenomenon of absolutely still days and breezy nights. The curves illustrate that this also causes higher average daily pond temperatures and is, by far, also the most thermally destabilizing condition. The case depicted of 12 hours of steady wind followed by 12 hours of absolute calm is rather extreme and can be viewed as a sort of limit for non-critical applications. These curves are also valuable in obtaining a general feel for pond reaction times under the most extreme conditions.

2. Atmospheric Solar Extinction: The reduction in solar energy due to atmospheric phenomenon is next in importance. However, since the curves represent the worst condition of full sun effect and since the capricious occurrence of solar reduction will only tend to make ponds cooler and generally more thermally stable, it was not worth depicting.

3. Absolute Humidity (Dew Point): This phenomenon ranks third in importance. It is generally a rather stable condition on a daily basis (not to be confused with wet-bulb temperature) and provides incremental leverage to pond surface cooling rates. The A Series of curves illustrates a daily variation in dew point, and the A thru C Series curves depict different dew point levels.

4. Air Temperatures (Dry and Wet Bulb): These also affect pond cooling. However, their importance is not very great. The effects of changes in dry bulb temperature is reduced by the difficulty in transmitting heat down into the pond surface. Although the wet bulb temperature theoretically sets the adiabatic limits of evaporative cooling, pond approach temperatures are not generally close enough to be seriously affected.

5. Pond Bottom Heating: Heating of the pond bottom to temperatures above water levels is due to direct absorption of solar energy at higher rates than can be transmitted to the pond water through the bottom film coefficient. This phenomenon rapidly

decreases with pond depth and turbidity. Its general effect in shallow ponds is to store heat for gradual release at night. This keeps ponds warm longer and helps to shave peaks in temperature thus contributing somewhat to thermal stability.

6. Turbidity: This contributes to greater temperature stratification in deeper ponds, but on the whole, little affects general performance within normal ranges.

SK/am
Attachments

cc: C. Anderson
L. Even
A. Glowacki
F. Krzich
J. Morphey
W. W. Nestander
T. Pawlak

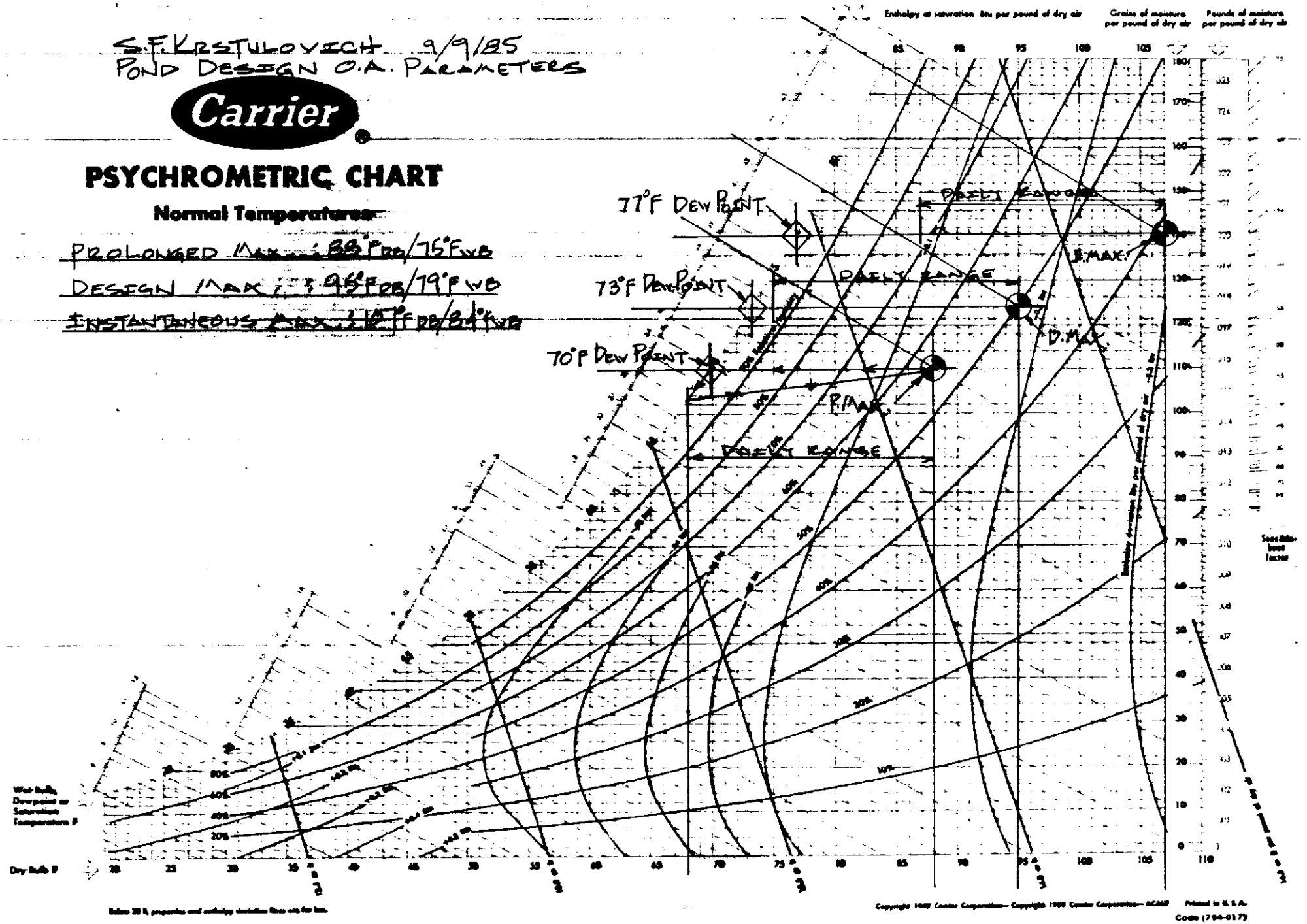
S.F. KRSTULOVICH 9/9/85
POND DESIGN O.A. PARAMETERS

Carrier

PSYCHROMETRIC CHART

Normal Temperatures

PROLONGED MAX. : 88°F DB/75°F WB
DESIGN MAX. : 95°F DB/79°F WB
INSTANTANEOUS MAX. : 105°F DB/81°F WB



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: COOLING POND PARAMETERS

NAME: S.F. KRESTULOVICH

DATE: 9.9.85

REVISION DATE:

SPECIFIC HEAT OF BOTTOM : ~.50
SPECIFIC GRAVITY OF BOTTOM : ~2.0
BOTTOM EMMISSIVITY & HEAT SINK COEFFICIENT : .3 BTU/SF/°F (~5%)
BOTTOM FILM U FACTOR : 5.5 BTU/SF/°F (~95%)

WIND FACTORS:

0 FPM (0 MPH) : AIR FILM U FACTOR = UP: 1.6 BTU/SF/°F & DN: 1.1 BTU/SF/°F
500 FPM (~5 MPH) : " = UP: 3.0 BTU/SF/°F & DN: 3.0 BTU/SF/°F
1000 FPM (~10 MPH) : " = UP: 5.0 BTU/SF/°F & DN: 5.0 BTU/SF/°F

DAILY TEMPERATURE RANGE : 20°F
SOLAR LATITUDE : 45° NORTH

POND MASS FACTORS:

100 LBS/SF = ~ 1'-6" DEEP (α LAYER)
200 LBS/SF = ~ 3'-0" DEEP (β LAYER)
300 LBS/SF = ~ 4'-6" DEEP (γ LAYER)
400 LBS/SF = ~ 6'-0" DEEP (δ LAYER)
500 LBS/SF = ~ 7'-6" DEEP (ε LAYER)

POND SOLAR ABSORBTION FACTOR (VARIES W/TURBIDITY): .5/100 LBS./SF.

α LAYER ABSORBTION : .500 W/ .500 BOT. FACTOR
β LAYER ABSORBTION : .250 W/ .250 BOT. FACTOR
γ LAYER ABSORBTION : .125 W/ .1.25 BOT. FACTOR
δ LAYER ABSORBTION : .063 W/ .062 BOT. FACTOR
ε LAYER ABSORBTION : .031 W/ .031 BOT. FACTOR

MAX. O.A. DESIGN PARAMETERS:

PROLONGED MAX. = 88°F DB / 75°F WB (70°F DEW POINT)
DESIGN MAX. = 95°F DB / 79°F WB (73°F DEW POINT)
INSTANTANEOUS MAX. = 107°F DB / 84°F WB (77°F DEW POINT)

DAILY SOLAR POND INPUT = 1938 BTU/SF

VP COEFFICIENTS : 0 FPM = 95 (100), 500 FPM = 308 (3.2x) (300), 1000 FPM = 520 (5.5x) (500)

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: Cooling Pond Daily Profiles

NAME: S.F. Krstulovich

DATE: 9.9.85

REVISION DATE:

DAILY POND PARAMETER PROFILES (AIR, SOLAR & BOTTOM)

		1	2	3	4	5	6 AM 6	7	8	9	10	11	NOON 12	13	14	15	16	17	6 PM 18	19	20	21	22	23	MIDN. 24
SOLAR TIME																									
AIR: PROLONGED MAX. CONDITIONS	DB	68	68	68	68	68	70	72	74	76	78	80	83	85	87	88	87	86	85	83	81	79	77	74	72
	WB	68	68	68	68	68	69	70	71	71	72	73	74	74	75	75	75	74	74	73	73	72	72	71	71
	DP/YP	68/.69	68/.69	68/.69	68/.69	68/.69	68/.69	69/.71	69/.71	69/.71	69/.71	69/.71	69/.71	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74	70/.74
AIR: DESIGN MAX. CONDITIONS	DB	75	75	75	75	75	77	79	81	83	85	87	90	92	94	95	94	93	92	90	88	86	84	81	79
	WB	74	74	74	74	74	74	75	75	75	76	77	78	78	79	79	79	78	78	77	77	76	76	75	75
	DP/YP	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82	73/.82
AIR: INSTANTANEOUS MAX. CONDITIONS	DB	87	87	87	87	87	89	91	93	95	97	99	102	104	106	107	106	105	104	102	100	98	96	93	91
	WB	79	79	79	79	79	79	80	80	80	81	82	83	83	84	84	84	83	83	82	82	81	81	80	80
	DP/YP	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94	77/.94
SUN: SOLAR AZIMUTH		—	—	—	—	—	73°	82°	94°	105°	120°	145°	180°	215°	239°	255°	268°	277°	287°	—	—	—	—	—	—
SUN: SOLAR ALTITUDE		—	—	—	—	—	16°	26°	37°	47°	57°	65°	68°	65°	57°	47°	37°	26°	16°	—	—	—	—	—	—
SUN: SOLAR BTU/SF NON-REFLECTED		—	—	—	—	—	36	84	134	175	204	221	228	223	204	175	134	84	36	—	—	—	—	—	—
POND BOTTOM: BOTTOM FACTORS FOR 1'6" DEEP POND	BTU ABSORBED	—	—	—	—	—	18	42	67	87	102	110	114	111	102	87	67	42	18	—	—	—	—	—	—
	TEMP. °F	79	78	77	76	75	76	77	79	81	83	89	95	99	104	107	108	108	108	105	102	98	94	89	85
	BTU TRANS. TO H_2O	22	16	11	5	0	5	5	16	22	27	55	82	104	132	154	165	170	176	165	148	126	104	77	55
POND BOTTOM: BOTTOM FACTORS FOR 3'0" DEEP POND	BTU ABSORBED	—	—	—	—	—	9	21	33	43	51	55	57	55	51	43	33	21	9	—	—	—	—	—	—
	TEMP. °F	76	76	75	75	75	75	75	76	76	77	78	80	81	82	83	83	83	83	82	81	81	80	78	77
	BTU TRANS. TO H_2O	5	5	0	0	0	0	0	0	0	0	0	0	5	11	22	27	33	38	38	33	33	27	16	11
POND BOTTOM: BOTTOM FACTORS FOR 4'6" DEEP POND	BTU ABSORBED	—	—	—	—	—	4	10	16	21	25	27	28	27	25	21	16	10	4	—	—	—	—	—	—
	TEMP. °F	76	76	75	75	75	75	75	76	76	77	78	79	80	81	81	81	80	79	78	78	78	78	77	77
	BTU TRANS. TO H_2O	5	5	0	0	0	0	0	0	0	0	0	0	0	5	11	16	16	16	16	16	16	16	11	11
POND BOTTOM: BOTTOM FACTORS FOR 6'0" DEEP POND	BTU ABSORBED	—	—	—	—	—	2	5	8	10	12	13	14	13	12	10	8	5	2	—	—	—	—	—	—
	TEMP. °F	75	75	75	75	75	75	75	75	75	76	76	77	77	78	78	78	78	77	77	77	76	76	76	76
	BTU TRANS. TO H_2O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	11	11	5	5	5	5
POND BOTTOM: BOTTOM FACTORS FOR 7'6" DEEP POND	BTU ABSORBED	—	—	—	—	—	1	2	4	5	6	6	7	6	6	5	4	2	1	—	—	—	—	—	—
	TEMP. °F	75	75	75	75	75	75	75	75	75	75	75	76	76	76	76	76	76	76	76	76	75	75	75	75
	BTU TRANS. TO H_2O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0
BOTTOM FILM REF. TEMP. °F		75	75	75	75	75	75	76	76	77	78	79	80	80	80	79	78	77	76	75	75	75	75	75	75

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: Cooling Pond Performance Profiles (Variable Wind Speeds)

NAME: S.F. Krstulovich

DATE: 9-9-85

REVISION DATE:

BTU WATER LOADING PER HUNDRED LB. MASS (95°FDB / 79°FWB)

	Wind MPH	0	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0
	Solar Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0 watts/sf	1'-6" Pond	17	9	6	0	-5	21	47	89	121	144	186	226	251	277	289	277	254	208	177	159	135	111	80	56
	3'-0" Pond	0	0	-2	-2	-2	12	30	50	72	80	88	95	98	98	96	83	67	39	25	22	21	15	9	6
	4'-6" Pond	0	0	-2	-2	-2	10	24	40	53	63	70	75	75	74	69	58	43	20	9	9	8	7	5	4
	6'-0" Pond	-1	-1	-1	-1	-1	8	19	33	43	51	56	60	60	58	52	42	32	13	6	5	4	3	2	1
	7'-6" Pond	-1	-1	-1	-1	-1	6	16	27	35	42	46	50	49	47	43	35	22	10	3	3	2	1	1	1
30 watts/sf	1'-6" Pond	120	110	110	100	100	120	150	190	220	250	290	330	350	380	390	380	360	310	280	260	240	210	180	160
	3'-0" Pond	50	50	50	50	50	60	80	100	120	130	140	150	150	150	150	130	120	90	80	70	70	70	60	60
	4'-6" Pond	35	35	35	35	35	45	60	75	90	100	105	110	110	110	105	95	80	55	45	45	45	40	40	40
	6'-0" Pond	25	25	25	25	25	35	45	60	70	75	80	85	85	85	75	65	55	40	30	30	30	30	25	25
	7'-6" Pond	20	20	20	20	20	25	35	45	55	60	65	70	70	65	65	55	40	30	25	25	20	20	20	20
60 watts/sf	1'-6" Pond	220	210	210	200	200	230	250	290	320	350	390	430	450	480	490	480	460	410	380	360	340	310	280	260
	3'-0" Pond	100	100	100	100	100	110	130	150	170	180	190	200	200	200	200	180	170	140	130	120	120	120	110	110
	4'-6" Pond	70	70	70	70	70	80	95	110	125	135	140	145	145	145	140	130	115	90	80	80	80	75	75	75
	6'-0" Pond	50	50	50	50	50	60	70	85	95	100	105	110	110	110	100	90	80	65	55	55	55	55	50	50
	7'-6" Pond	40	40	40	40	40	45	55	65	75	80	85	90	90	85	85	75	60	50	45	45	40	40	40	40

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: POND STRATIFIED DAILY PROFILES

NAME: S.F. KRSTULOVICH

DATE: 9.9.85

REVISION DATE:

DAILY POND WATER STRATIFICATION PARAMETERS PROFILE (SENSIBLE AIR & SOLAR GAINS)

		SOLAR TIME	1	2	3	4	5	6 AM 6	7	8	9	10	11	NOON 12	13	14	15	16	17	6 PM 18	19	20	21	22	23	MIDN. 24
STRATIFIED SOLAR WATER GAIN	α LAYER 0 TO 1'-6"	SOLAR BTU	—	—	—	—	—	18	42	67	87	102	110	114	111	102	87	67	42	18	—	—	—	—	—	—
		LAYER TRANS BTU	-2	-2	-2	-2	-2	-2	-4	-7	-9	-10	-11	-11	-11	-10	-9	-7	-4	-2	-2	-2	-2	-2	-2	-2
		NET BTU EFFECT	-2	-2	-2	-2	-2	16	38	60	78	92	99	103	100	92	78	60	38	16	-2	-2	-2	-2	-2	-2
	β LAYER 1'-6" TO 3'-0"	SOLAR BTU	—	—	—	—	—	9	21	33	43	51	55	57	55	51	43	33	21	9	—	—	—	—	—	—
		LAYER TRANS BTU	1	1	1	1	1	1	2	4	5	5	6	6	6	5	5	4	2	1	1	1	1	1	1	1
		NET BTU EFFECT	1	1	1	1	1	10	23	37	48	56	61	63	61	56	48	37	23	10	1	1	1	1	1	1
	γ LAYER 3'-0" TO 4'-6"	SOLAR BTU	—	—	—	—	—	4	10	16	21	25	27	28	27	25	21	16	10	4	—	—	—	—	—	—
		LAYER TRANS BTU	1	1	1	1	1	1	1	2	2	3	3	3	3	3	2	2	1	1	1	1	1	1	1	1
		NET BTU EFFECT	1	1	1	1	1	5	11	18	23	28	30	31	30	28	23	18	11	5	1	1	1	1	1	1
	δ LAYER 4'-6" TO 6'-0"	SOLAR BTU	—	—	—	—	—	2	5	8	10	12	13	14	13	12	10	8	5	2	—	—	—	—	—	—
		LAYER TRANS BTU	—	—	—	—	—	—	1	1	1	1	1	1	1	1	1	1	1	—	—	—	—	—	—	—
		NET BTU EFFECT	—	—	—	—	—	2	6	9	11	13	14	15	14	13	11	9	6	2	—	—	—	—	—	—
	ε LAYER 6'-0" TO 7'-6"	SOLAR BTU	—	—	—	—	—	1	2	4	5	6	6	7	6	6	5	4	2	1	—	—	—	—	—	—
		LAYER TRANS BTU	—	—	—	—	—	—	—	—	1	1	1	1	1	1	1	—	—	—	—	—	—	—	—	—
		NET BTU EFFECT	—	—	—	—	—	1	2	4	6	7	7	8	7	7	6	4	2	1	—	—	—	—	—	—
SENSIBLE AIR GAIN	PROLONGED MAX. AIR BTU GAIN 88°F DB/75	0 MPH WIND	-11	-11	-11	-11	-11	-8	-6	-3	0	1	3	7	9	11	13	12	11	10	8	7	4	2	-2	-5
		5 MPH WIND	-21	-21	-21	-21	-21	-15	-12	-6	0	3	9	18	24	30	36	33	30	27	21	18	12	6	-3	-9
		10 MPH WIND	-35	-35	-35	-35	-35	-25	-20	-10	0	5	15	30	40	50	60	55	50	45	35	30	20	10	-5	-15
		AIR FILM REF °F	75	75	75	75	75	75	76	76	76	77	77	77	77	77	76	76	76	76	76	75	75	75	75	75
		AIR FILM ΔT	-7	-7	-7	-7	-7	-5	-4	-2	0	1	3	6	8	10	12	11	10	9	7	6	4	2	-1	-3
	DESIGN MAX. AIR BTU GAIN 95°F DB/79	0 MPH WIND	-5	-5	-5	-5	-5	-2	0	2	4	6	8	11	13	15	18	17	15	14	12	11	9	7	3	1
		5 MPH WIND	-9	-9	-9	-9	-9	-3	0	6	12	15	21	30	36	42	48	45	42	39	33	30	24	18	9	3
		10 MPH WIND	-15	-15	-15	-15	-15	-5	0	10	20	25	35	50	60	70	80	75	70	65	55	50	40	30	15	5
		AIR FILM REF °F	78	78	78	78	78	78	79	79	79	80	80	80	80	80	79	79	79	79	79	78	78	78	78	78
		AIR FILM ΔT	-3	-3	-3	-3	-3	-1	0	2	4	5	7	10	12	14	16	15	14	13	11	10	8	6	3	1
α LAYER	INSTANT. MAX. AIR BTU GAIN 107°F DB/84	0 MPH WIND	6	6	6	6	6	8	9	11	13	14	17	20	22	24	26	25	24	23	21	20	18	15	12	10
		5 MPH WIND	15	15	15	15	15	21	24	30	36	39	45	54	60	66	72	69	66	63	57	54	48	42	33	27
		10 MPH WIND	25	25	25	25	25	35	40	50	60	65	75	90	100	110	120	115	110	105	95	90	80	70	55	45
		AIR FILM REF °F	82	82	82	82	82	82	83	83	83	84	84	84	84	84	83	83	83	83	83	82	82	82	82	82
		AIR FILM ΔT	5	5	5	5	5	7	8	10	12	13	15	18	20	22	24	23	22	21	19	18	16	14	11	9

III

Cooling Pond Performance Criteria Graphs

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		1'6" DEEP POND	1A

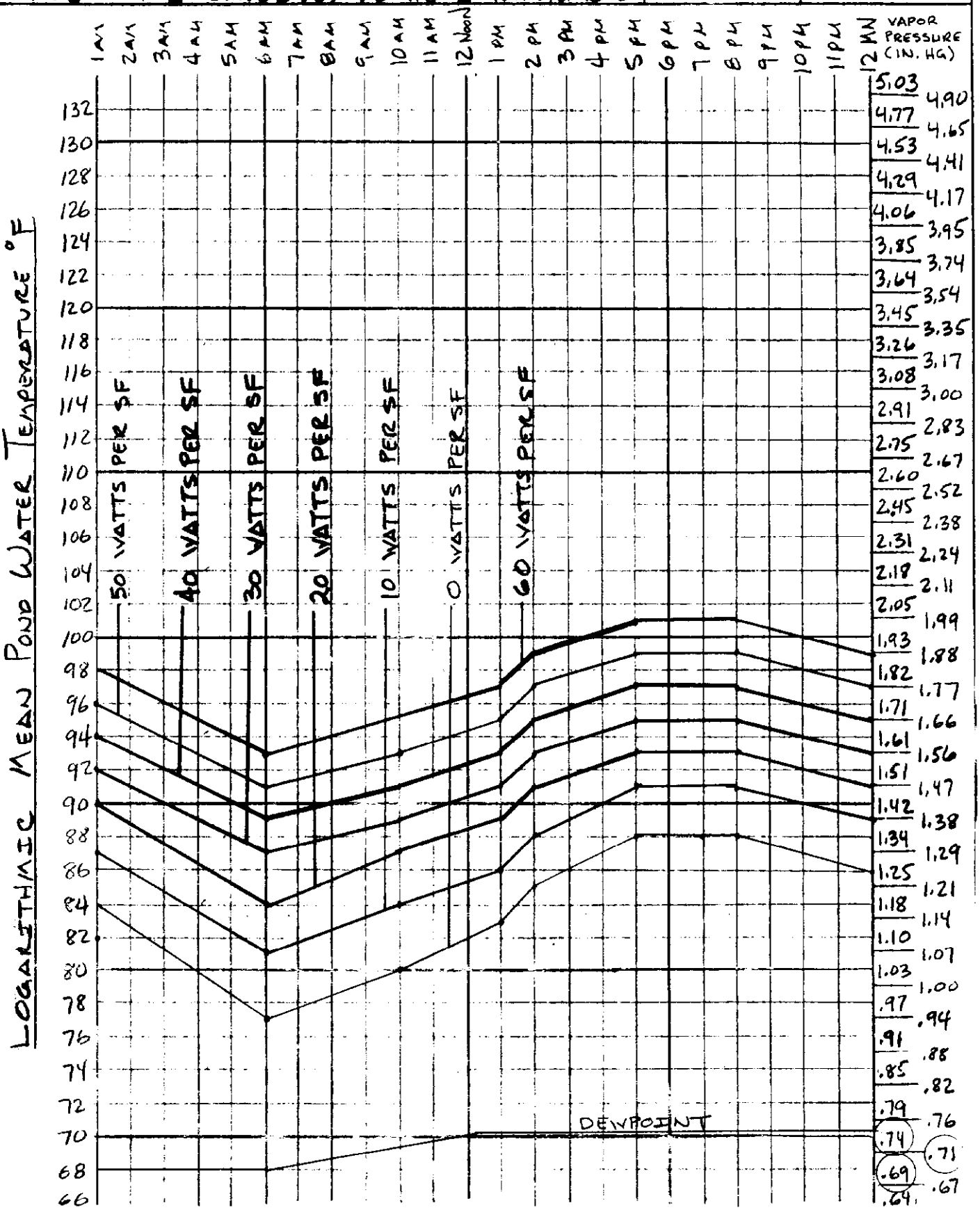
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 88 DB / 75 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		DEEP POND	1B

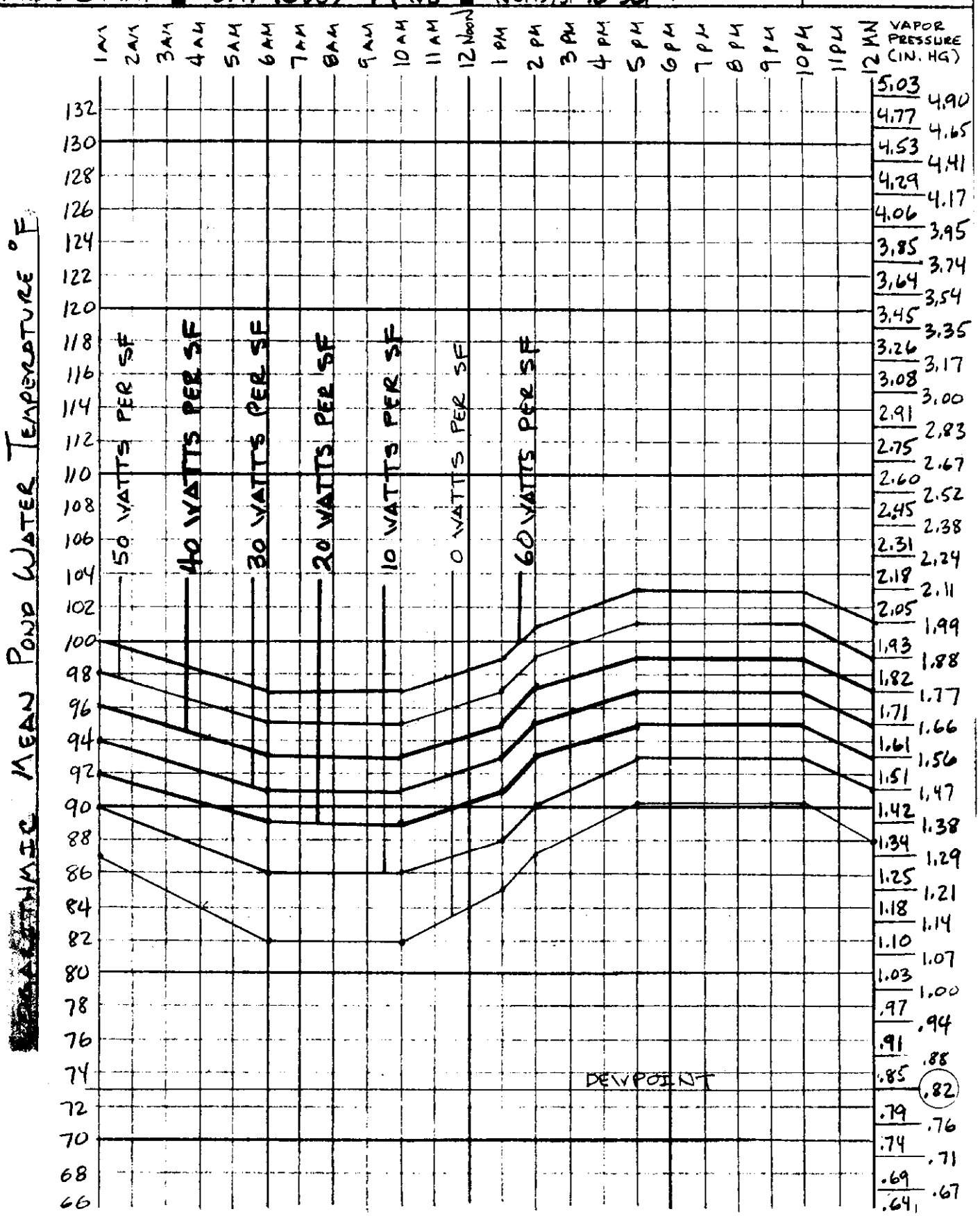
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		1-6 DEEP POND	1C

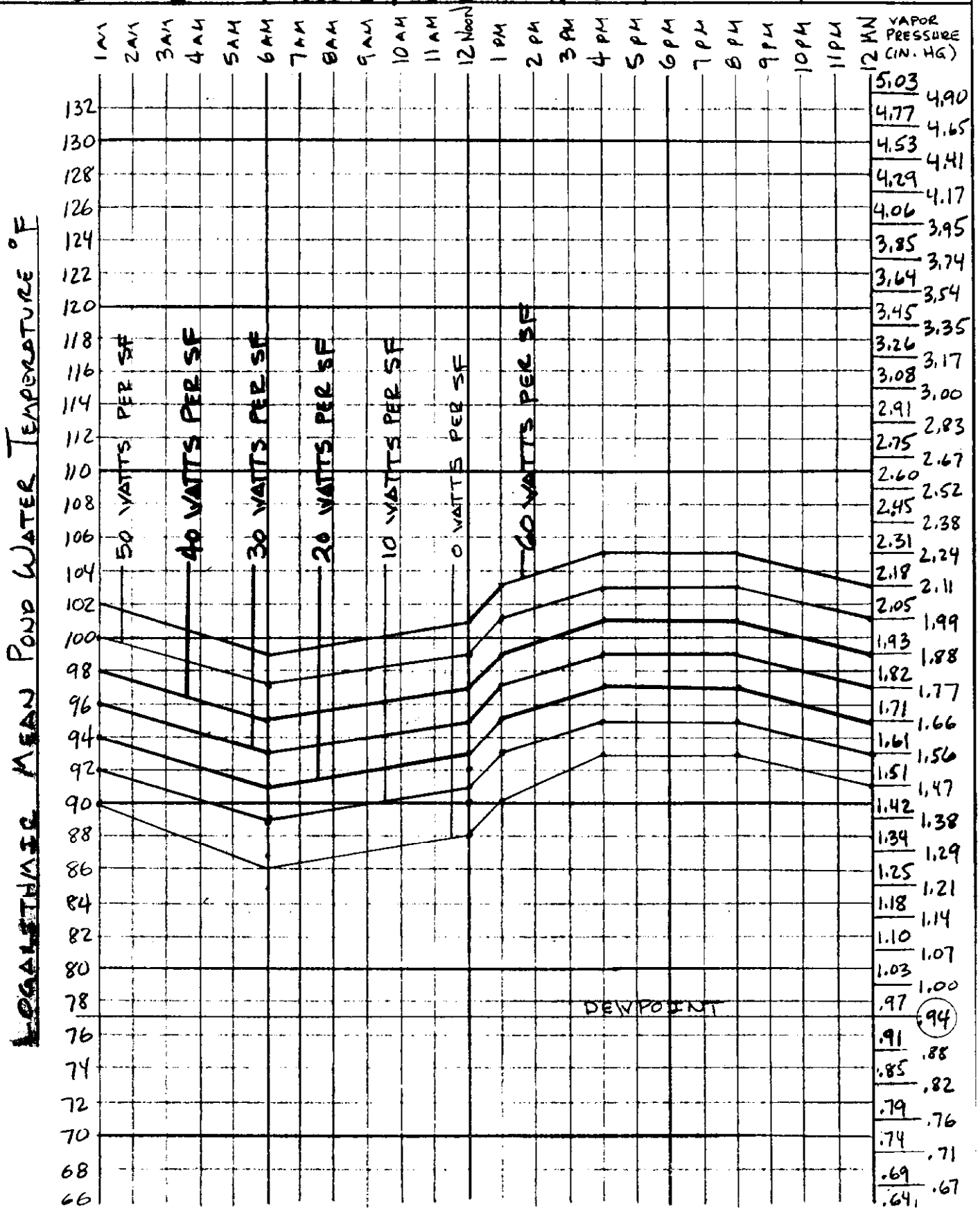
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 107 DB / 84 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		DEEP POND	1D

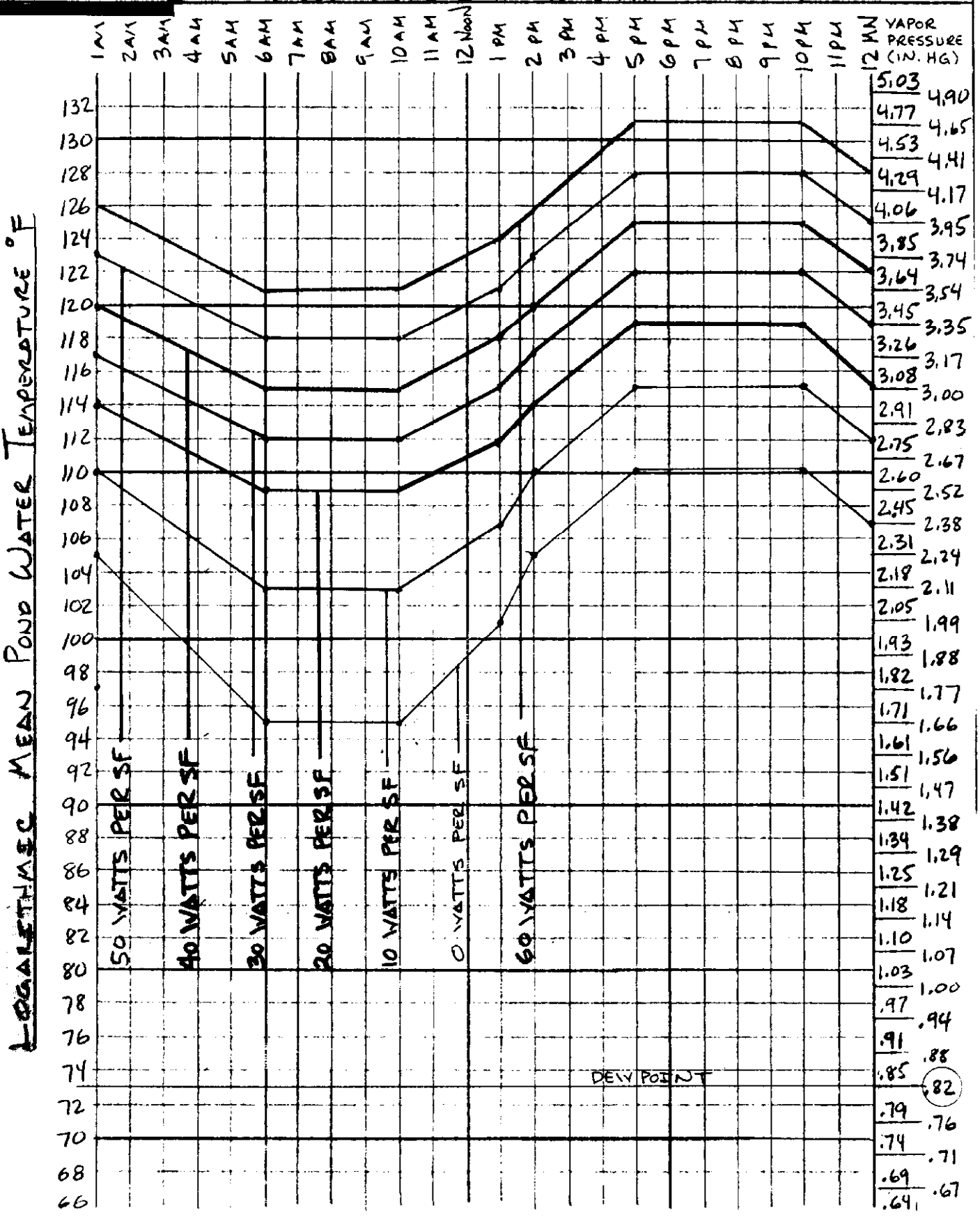
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0 MPH | OA: 95DB / 79WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		DEEP POND	1E

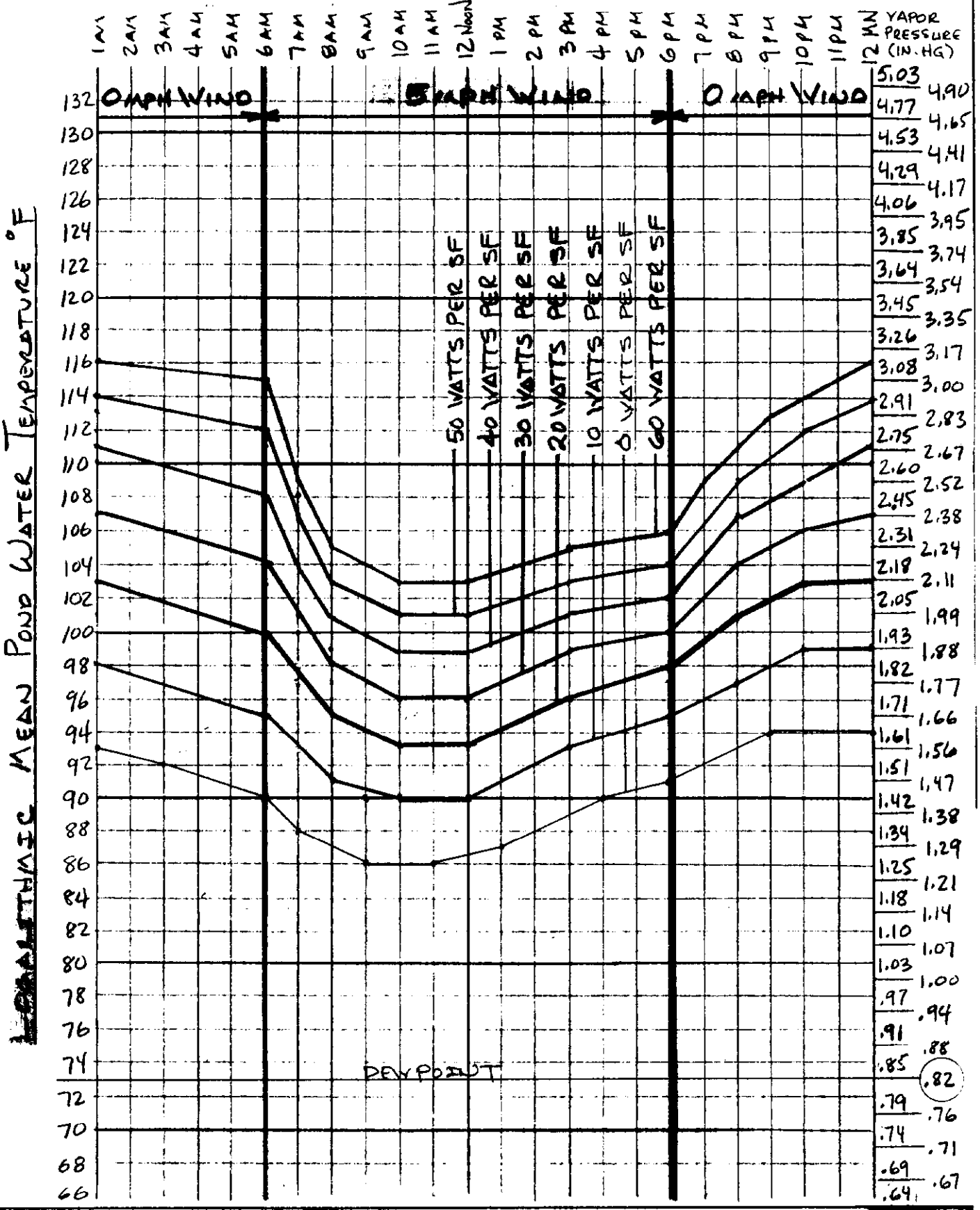
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0-5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



DAY WIND VARIABILITY EFFECT

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		1'-6" DEEP POND	1F

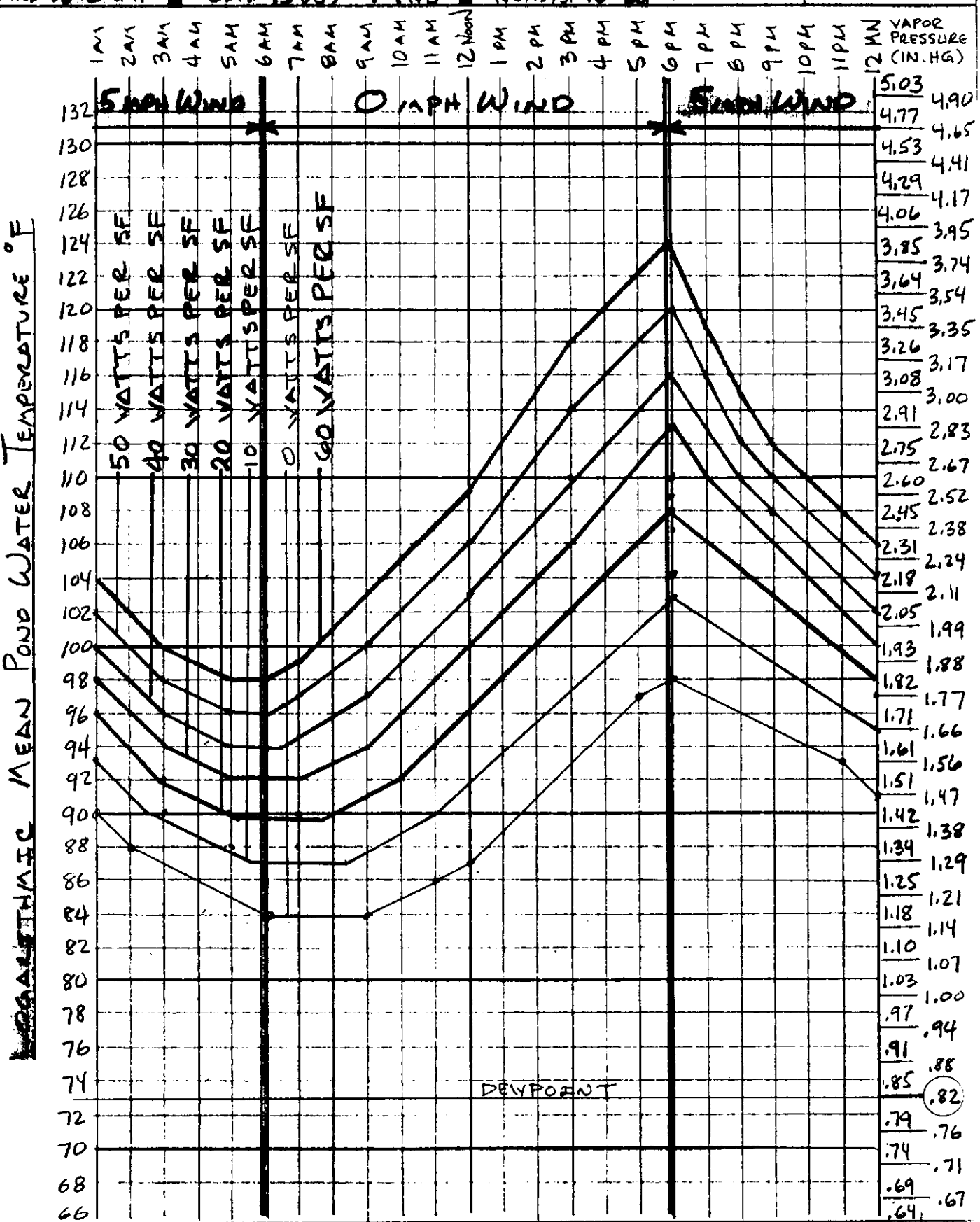
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5-0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



NIGHT WIND VARIABILITY EFFECT

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		210 DEEP POND	2A

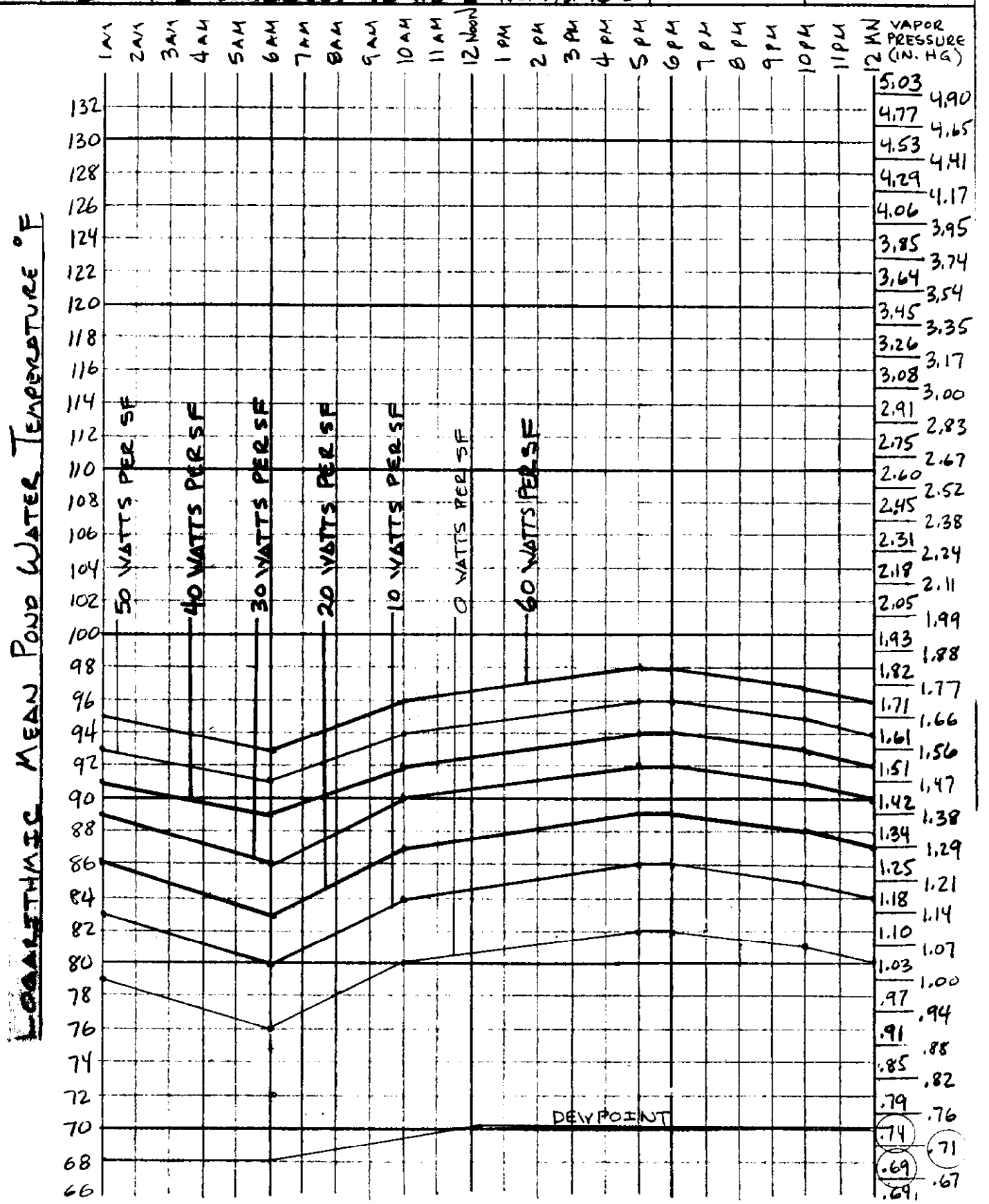
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 88 DB / 75 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		"3L0" DEEP POND	2B

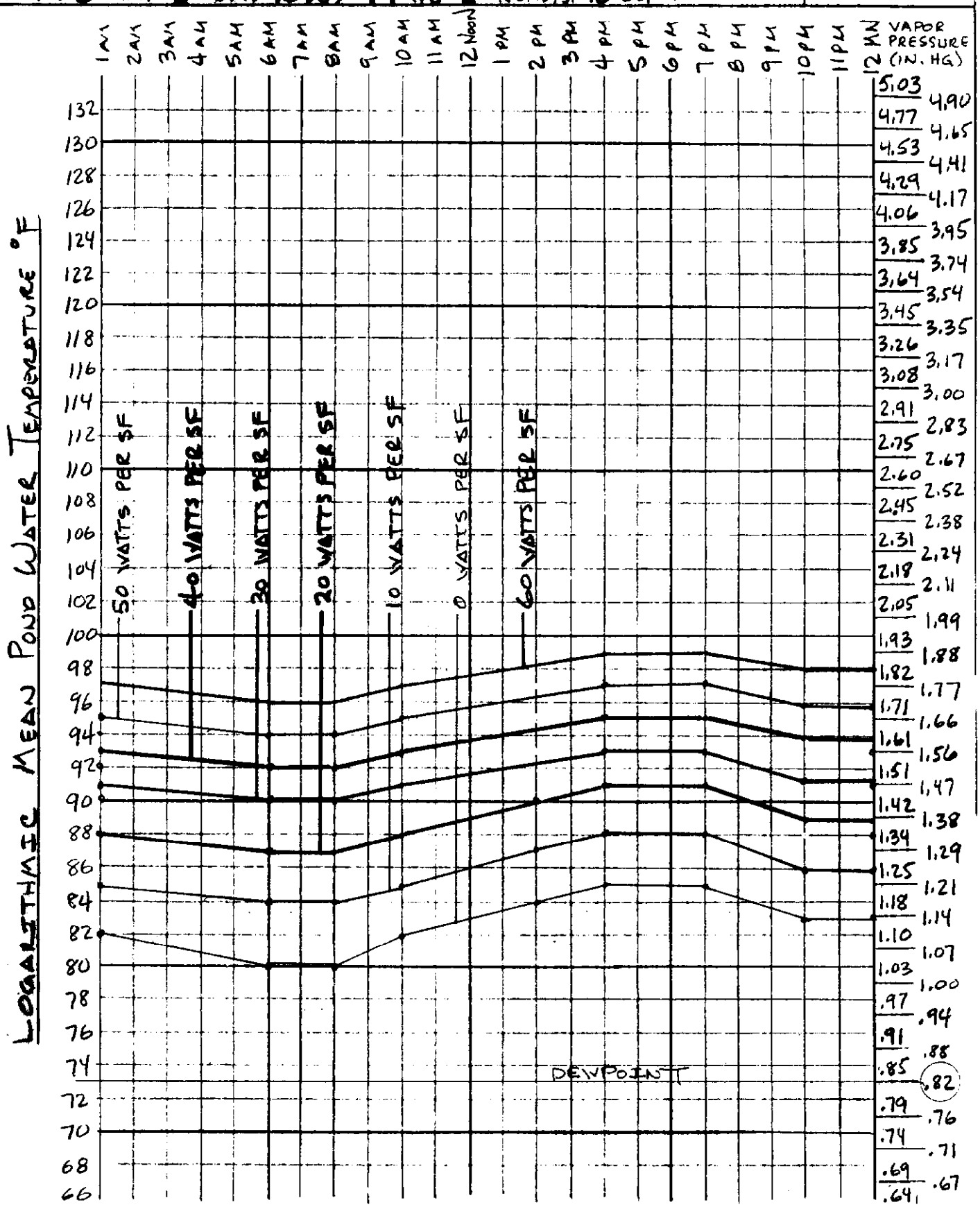
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		3-0H DEEP POND	2C

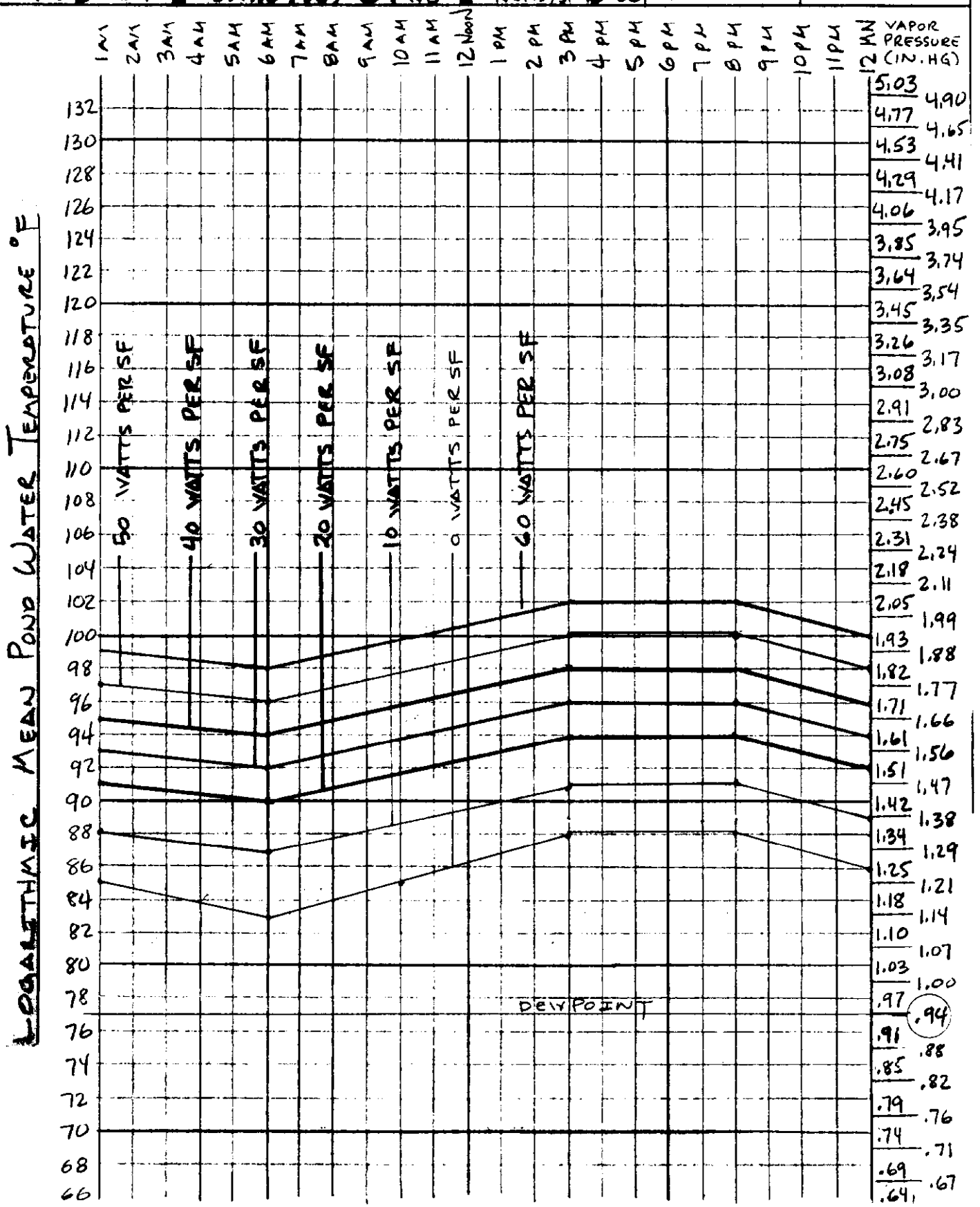
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 107 DB / 84 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		31-0 DEEP POND	2D

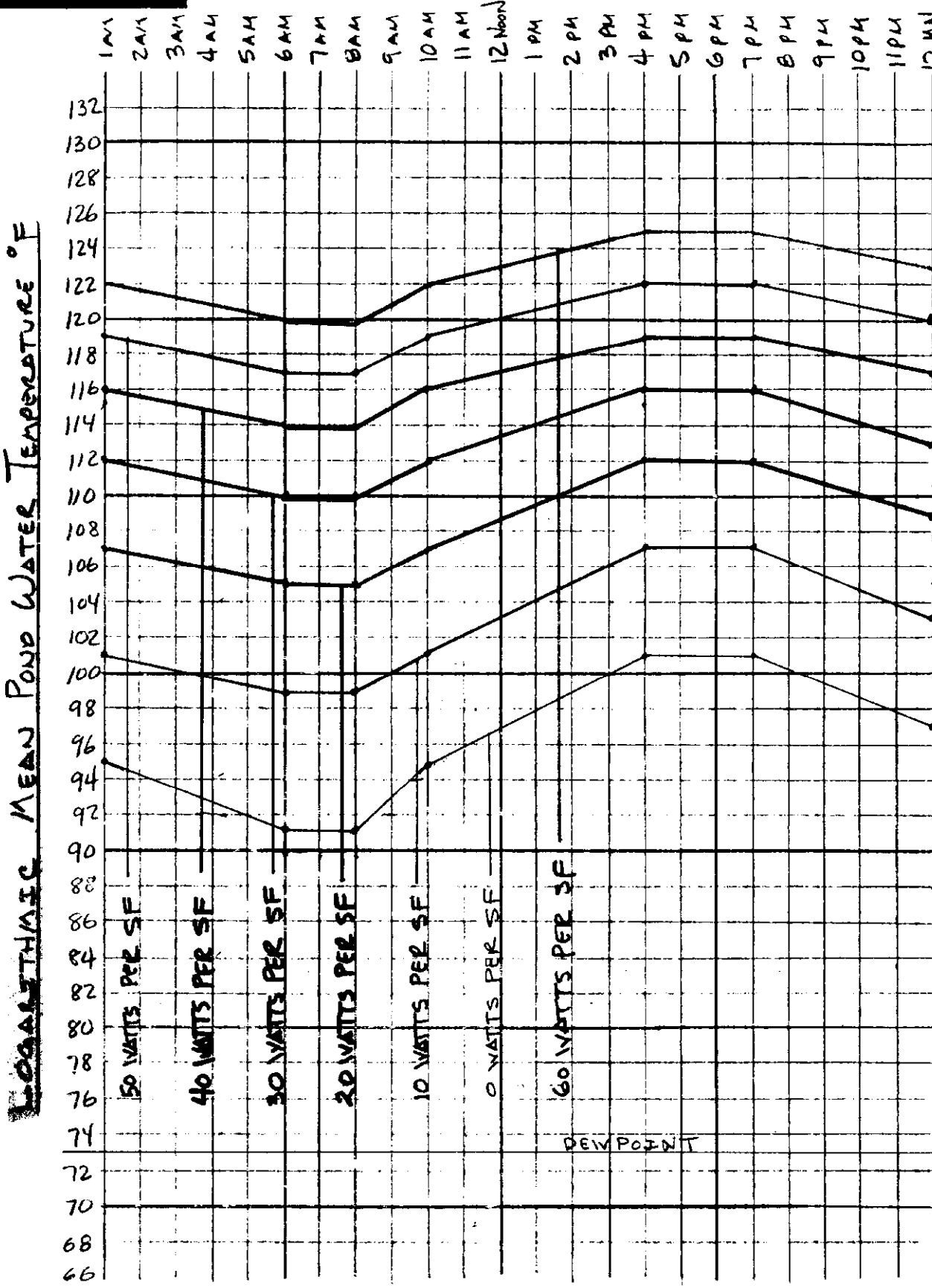
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND 10 MPH | OAT 95 DB / 79 WB | WATTS/SF : 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		DEEP POND	2E

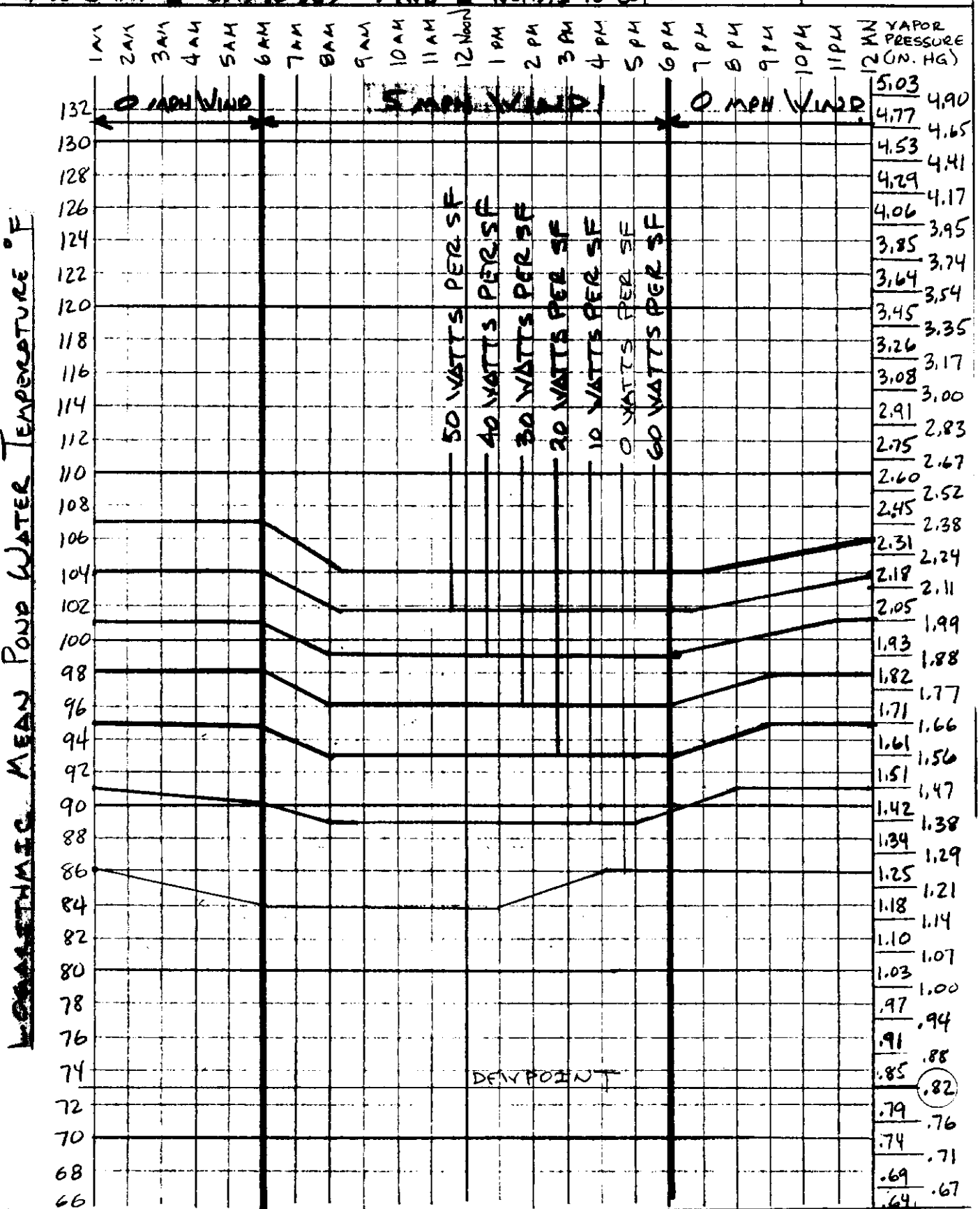
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0-5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



DAY WIND VARIABILITY EFFECT

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		DEEP POND	2 F

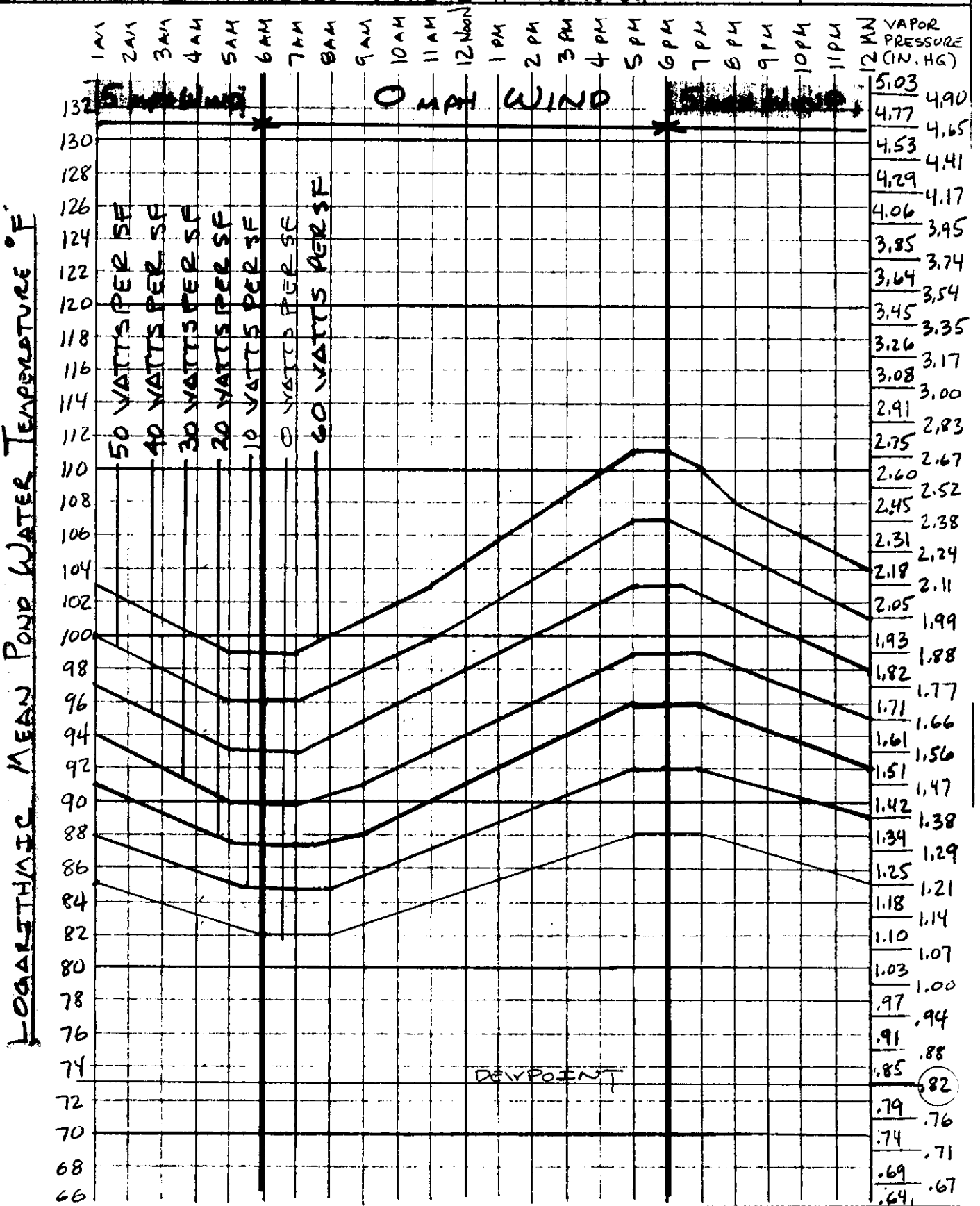
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND 15-0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



NIGHT WIND VARIABILITY EFFECT

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		4'-6" DEEP POND	3A

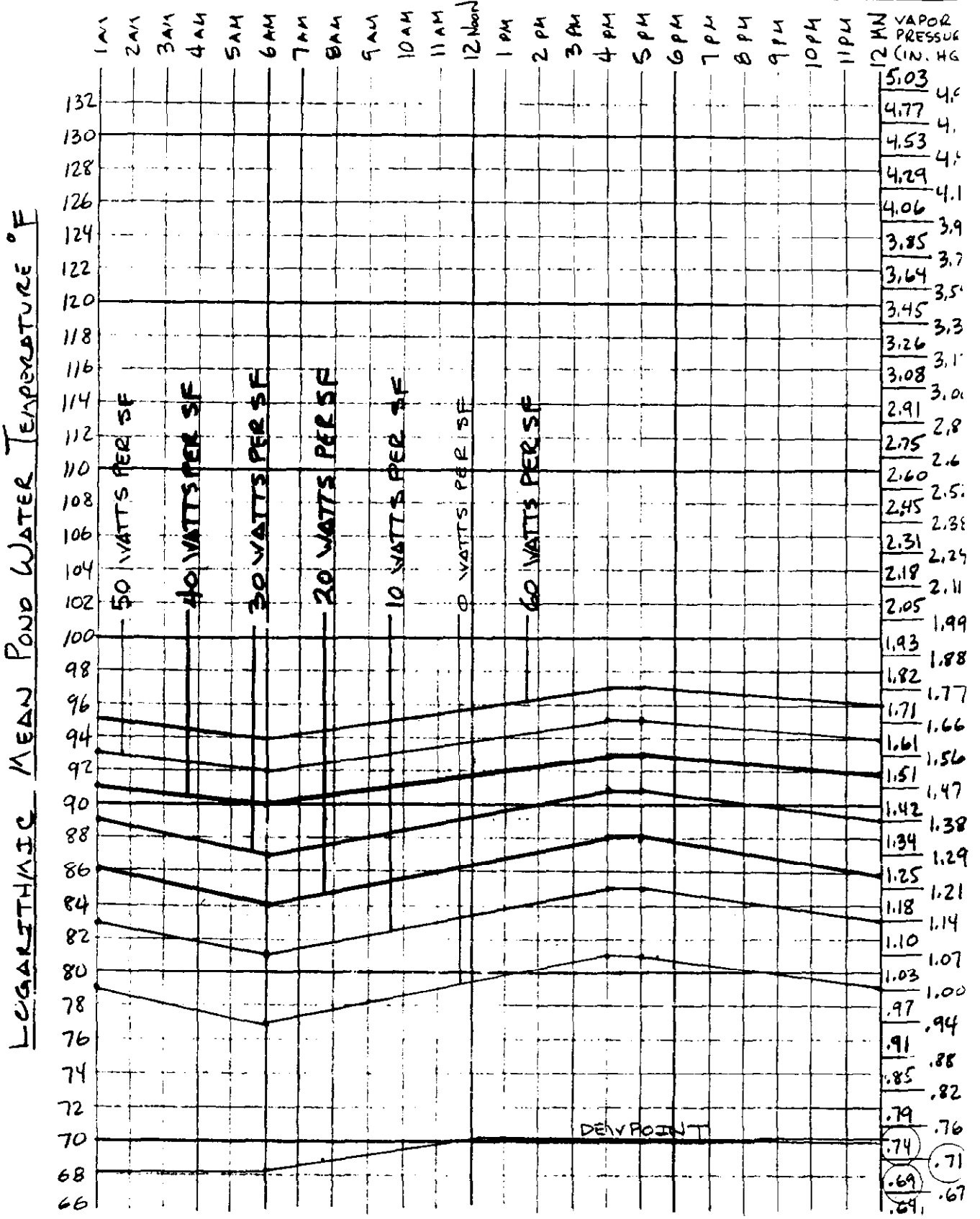
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 88 DB / 75 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		4'-6" DEEP POND	3B

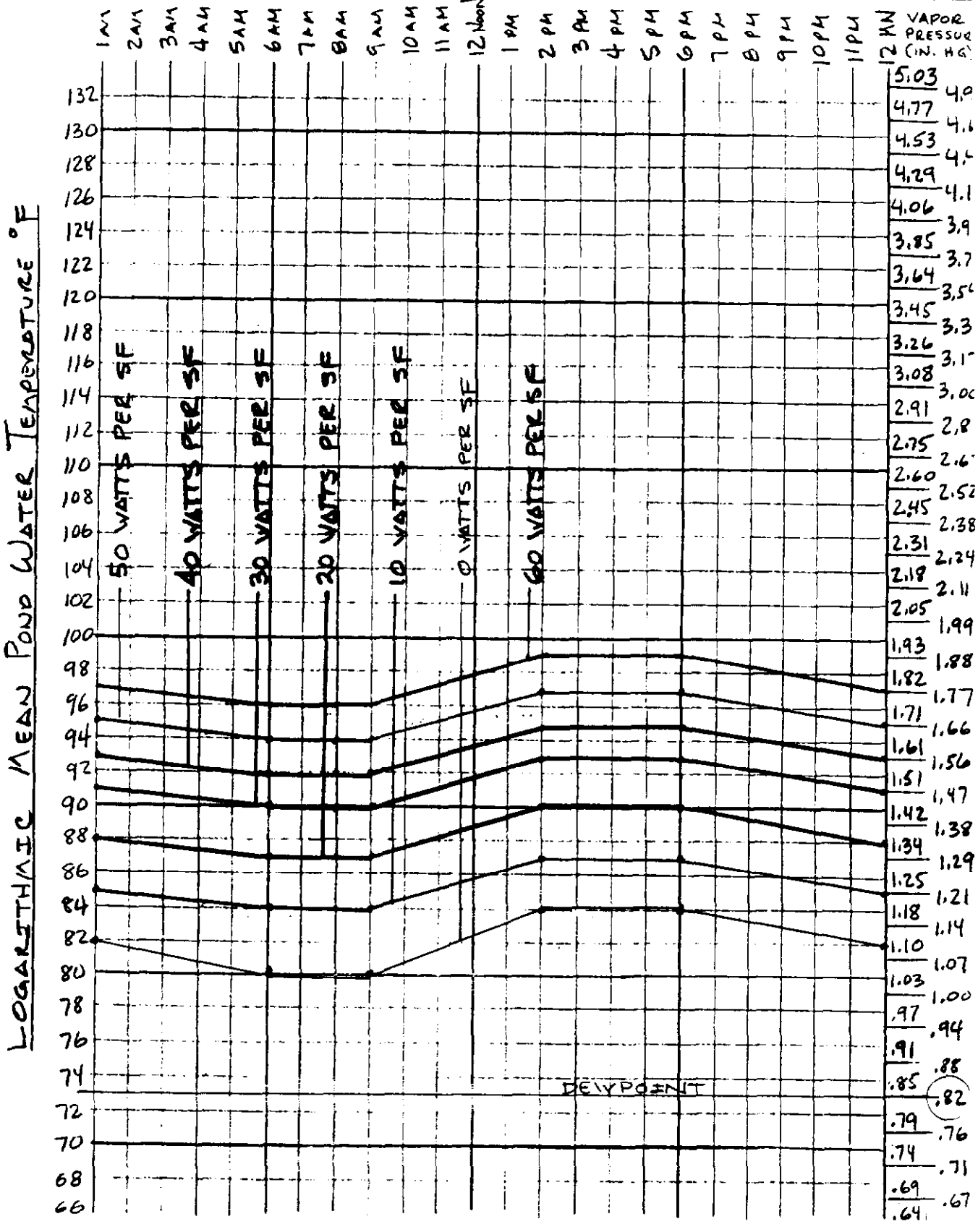
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		4'-6" DEEP POND	3C

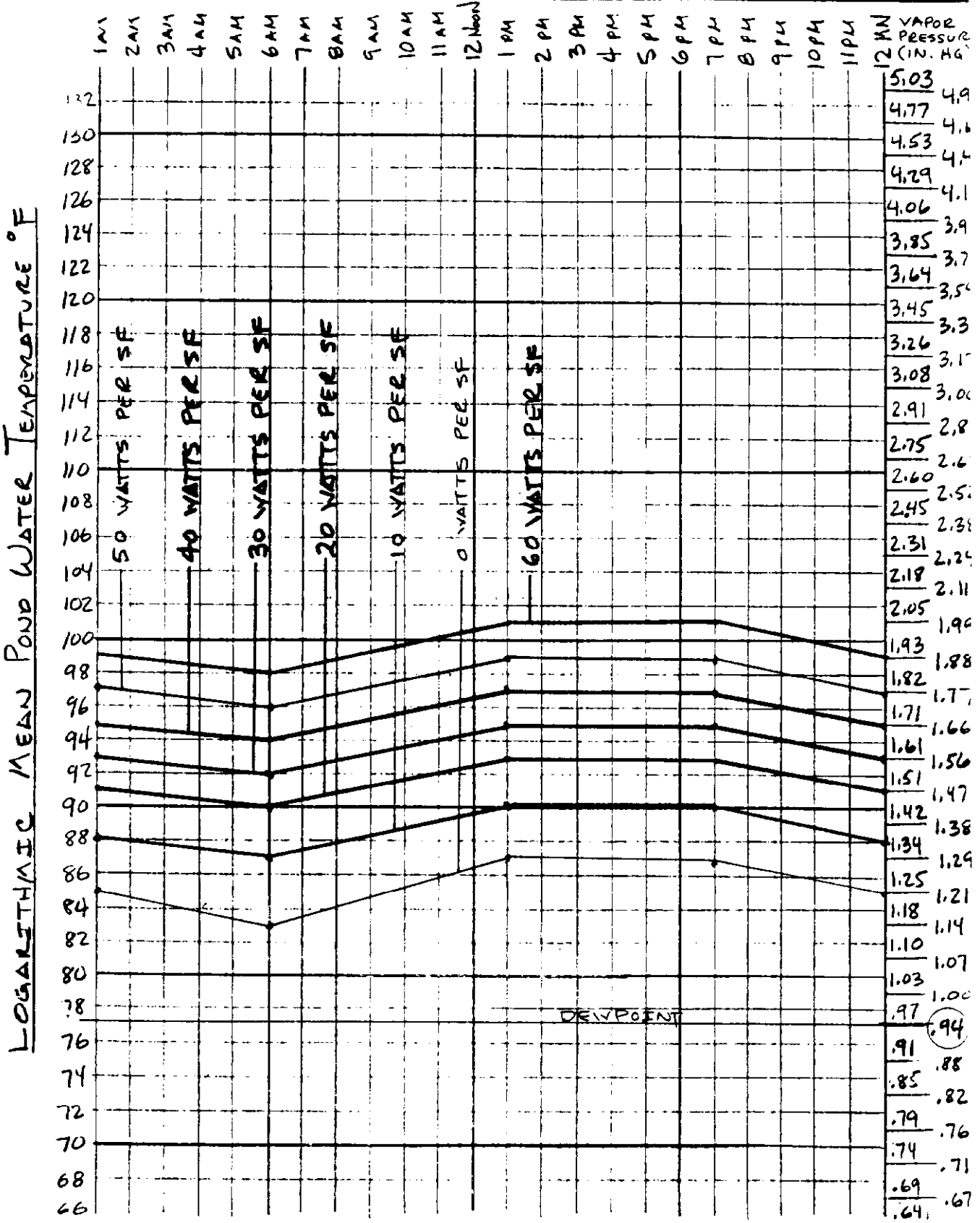
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 107 DB / 84 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		4'-6" DEEP POND	3D

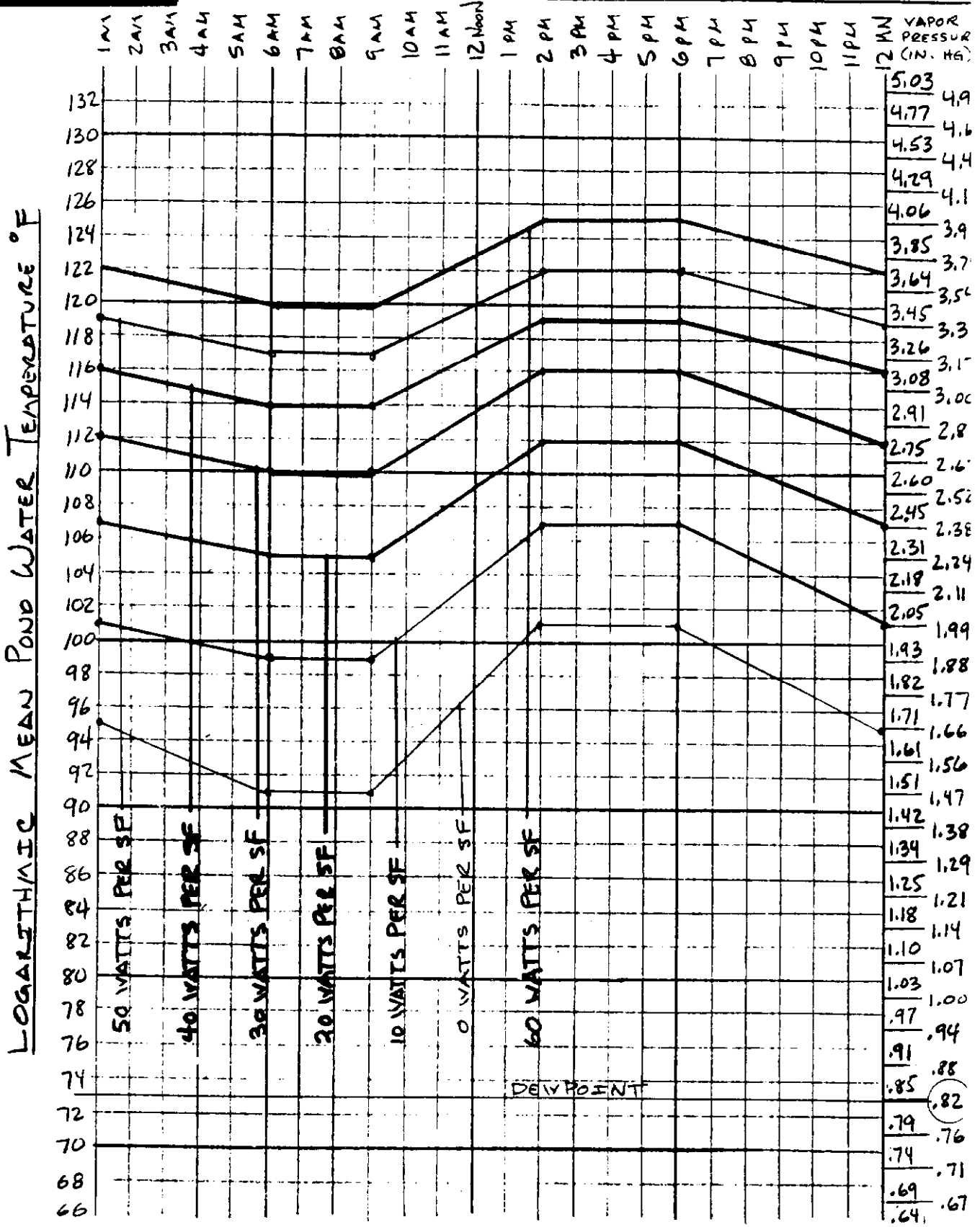
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		4"-6" DEEP POND	3E

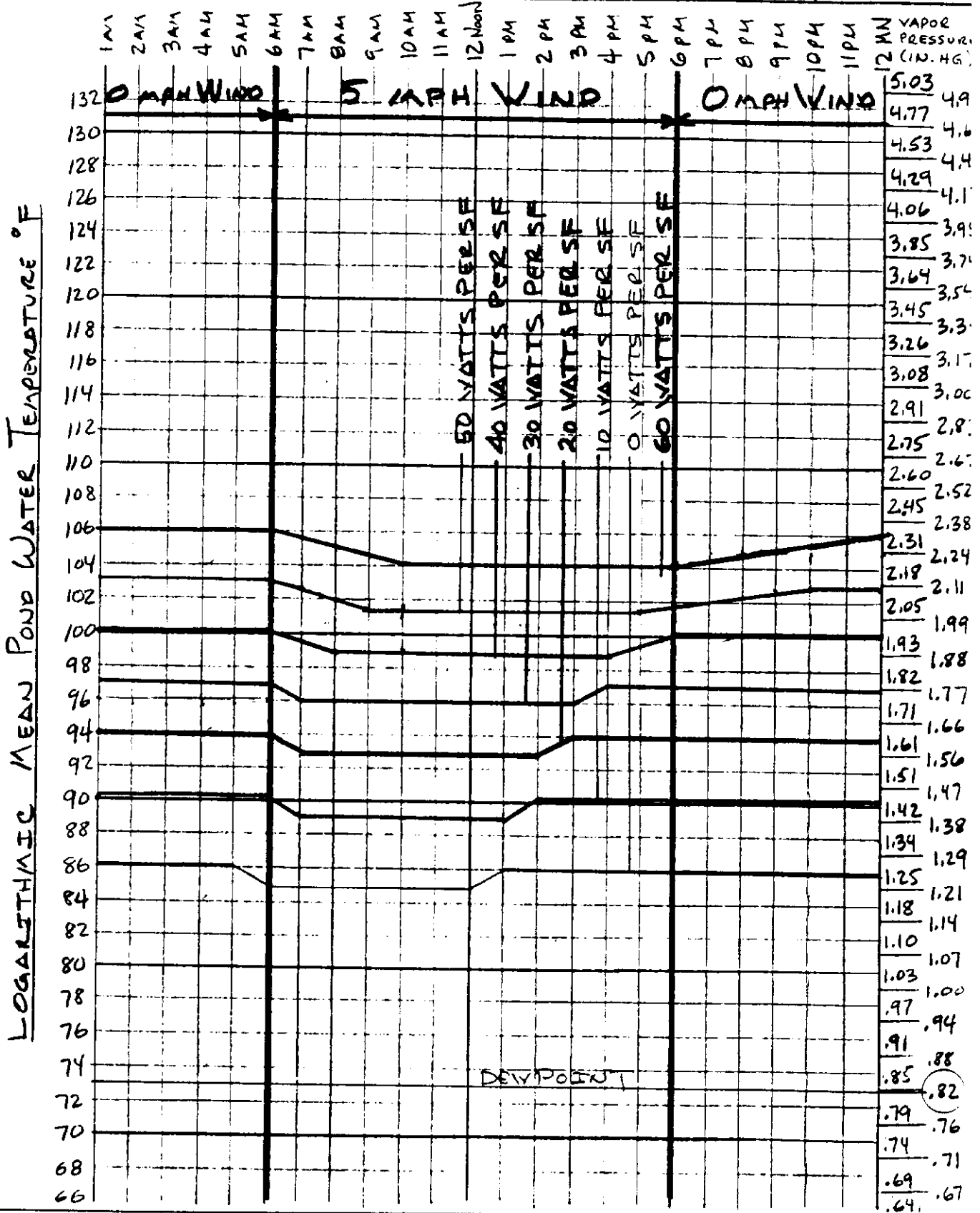
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0-5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



DAY WIND VARIABILITY EFFECTS

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		4'-6" DEEP POND	3F

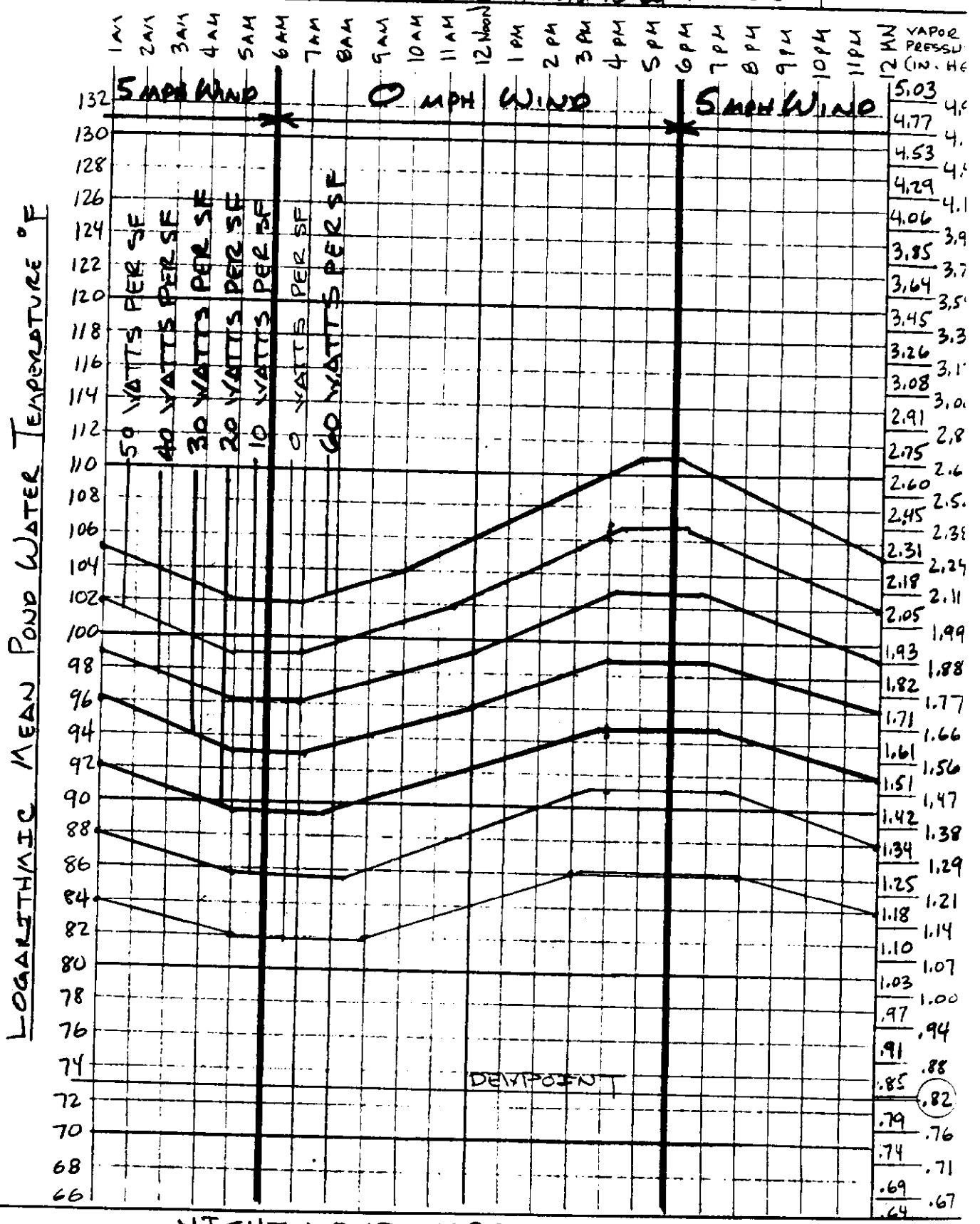
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5-0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



NIGHT WIND VARIABILITY EFFECT

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		60" DEEP POND	4A

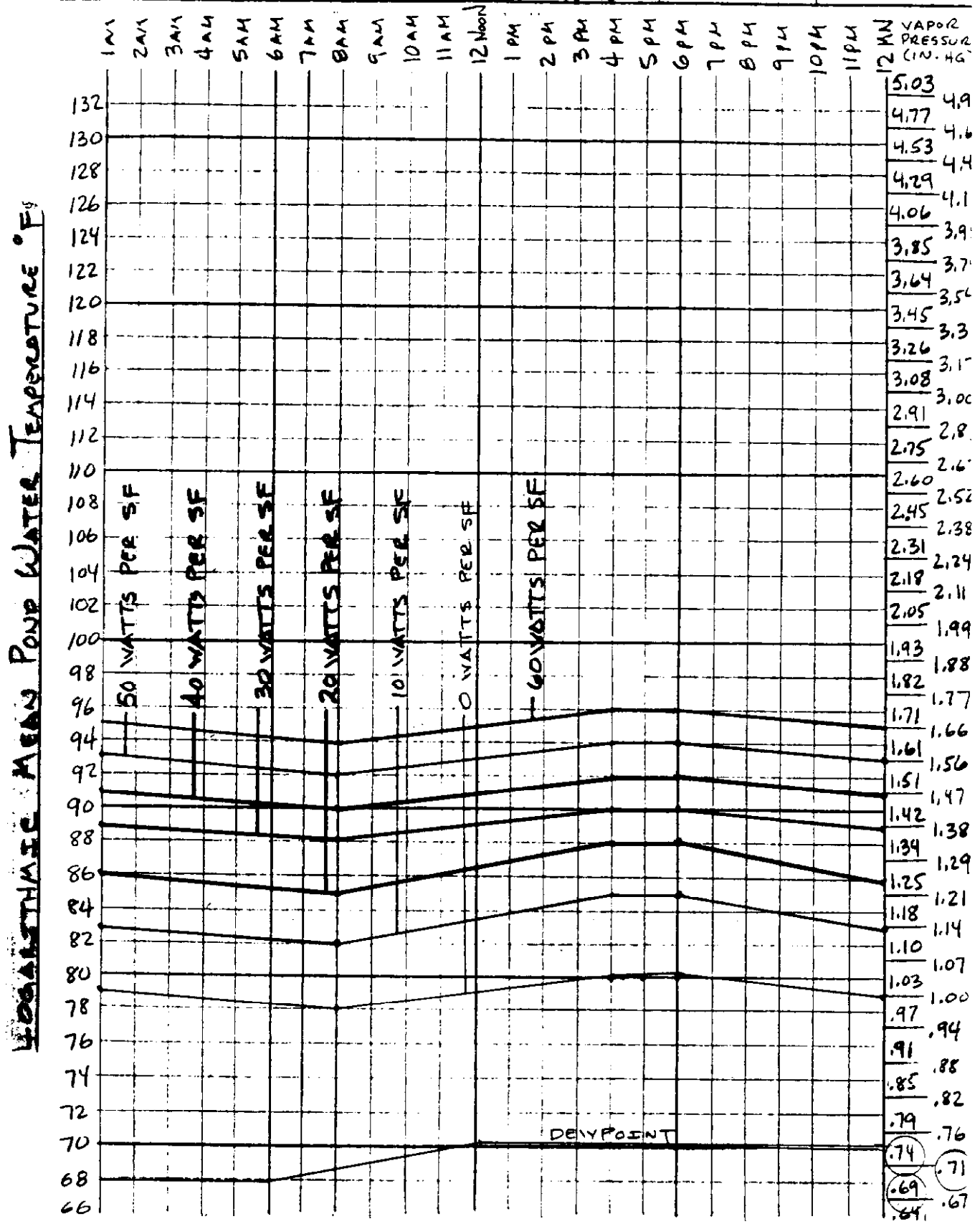
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 88 DB / 75 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

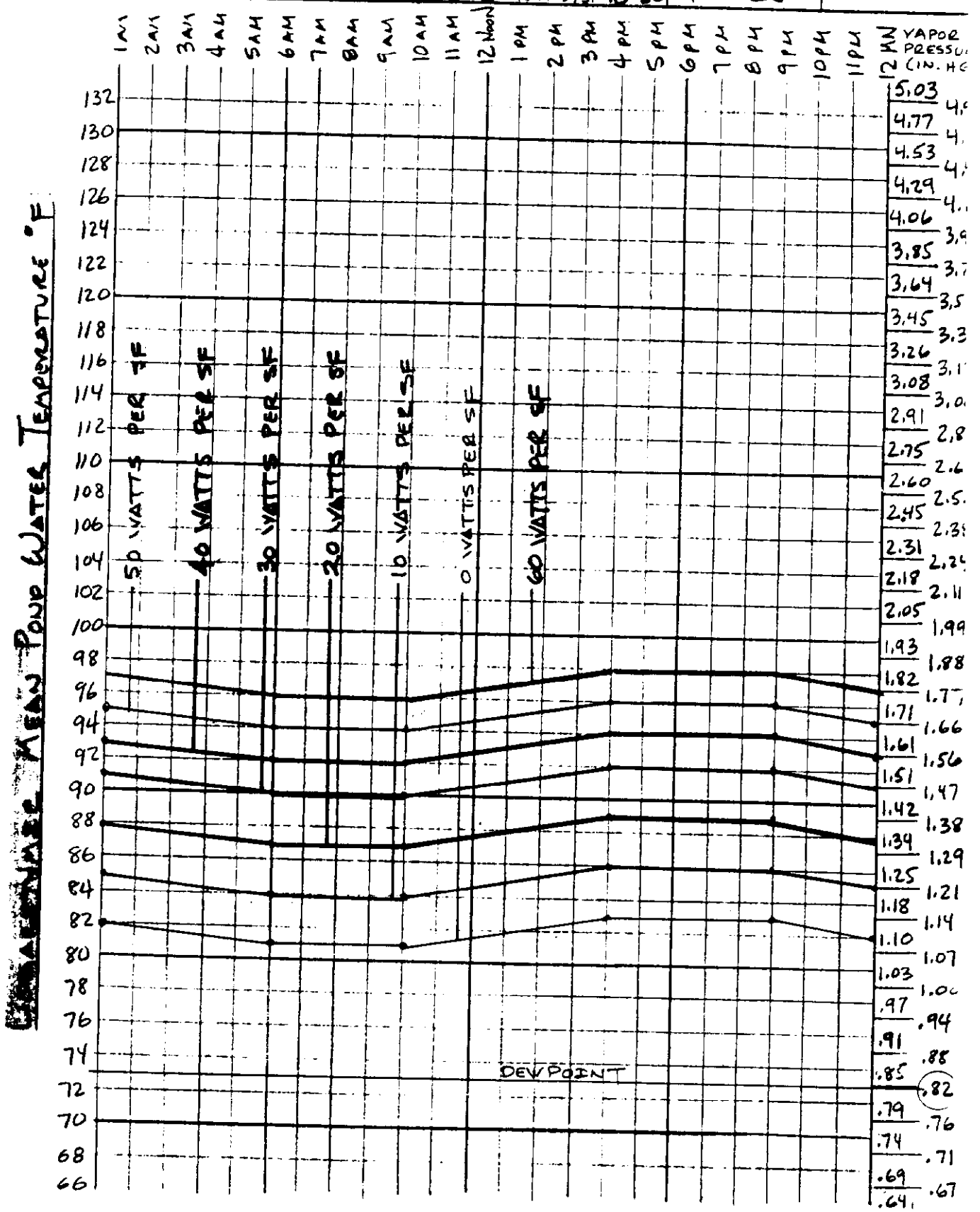
SECTION | PROJECT | SERIAL-CATEGORY: DEEP POND | PAGE 4B

SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

WIND: 5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50

DATE: 9-10-85 | REVISION DATE



FERMILAB
ENGINEERING NOTE

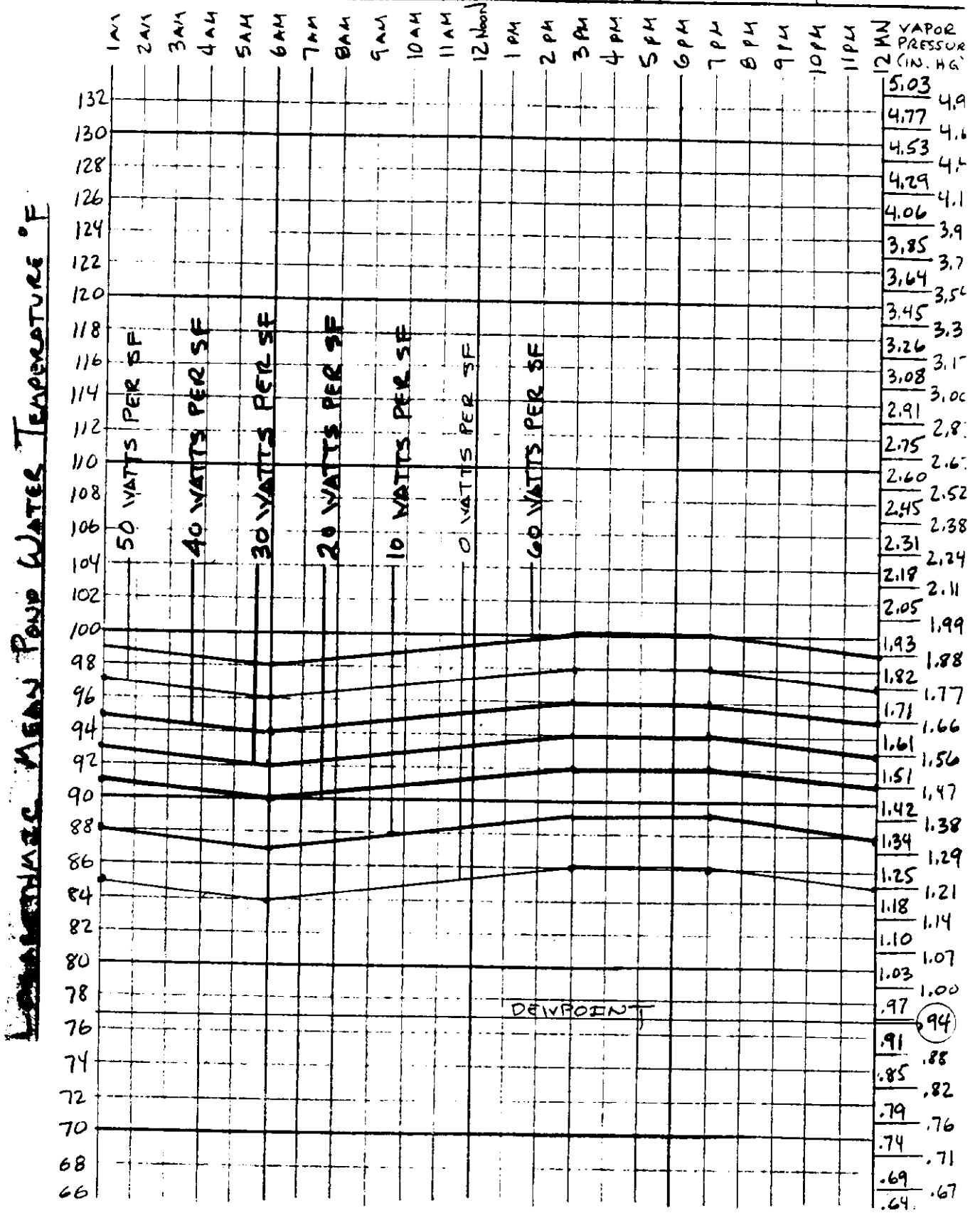
SECTION | PROJECT | SERIAL-CATEGORY 210 DEEP POND | PAGE 4C

SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85 | REVISION DATE

WIND: 5 MPH | OA: 107 DB / 84 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

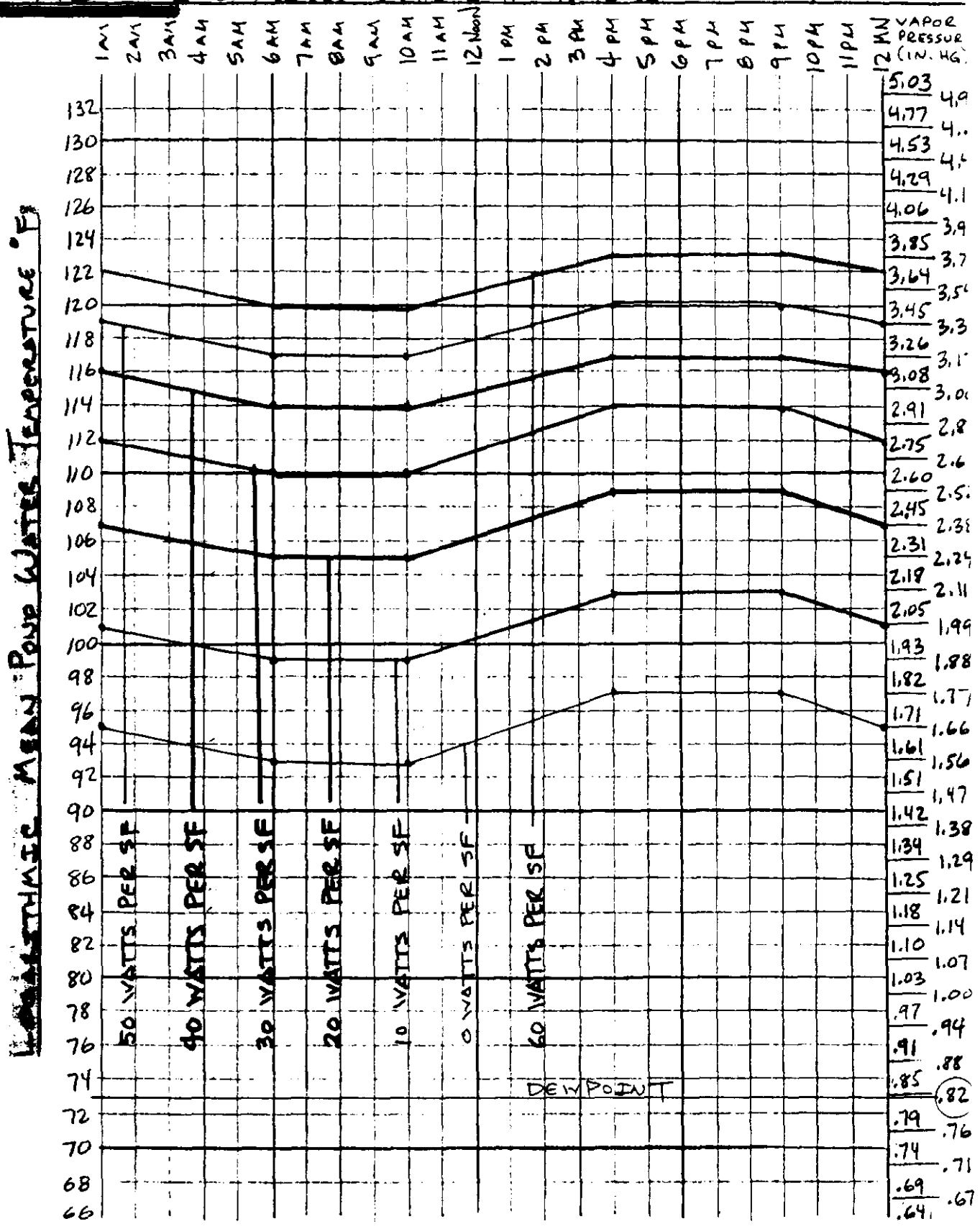
SECTION | PROJECT | SERIAL-CATEGORY CLO DEEP POND | PAGE 4D

SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85 | REVISION DATE

WIND: 0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

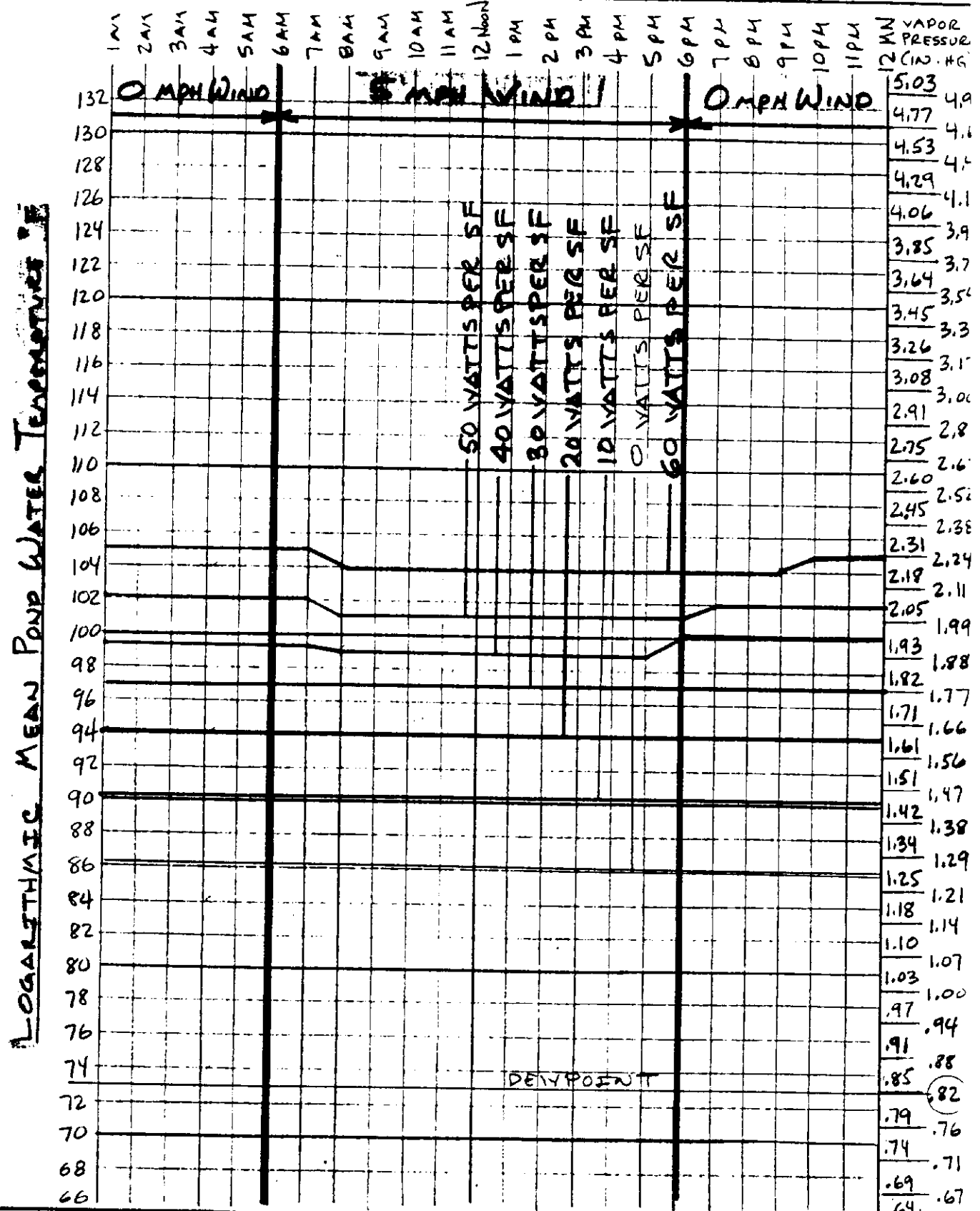
SECTION | PROJECT | SERIAL NUMBER: DEEP POND | PAGE 4E

SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

WIND: 0-5MPH | OA: 95DB / 79WB | WATTS/SF: 0-60

DATE: 9-10-85 | REVISION DATE



DAY WIND VARIABILITY EFFECTS

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		6-0 DEEP POND	4 F

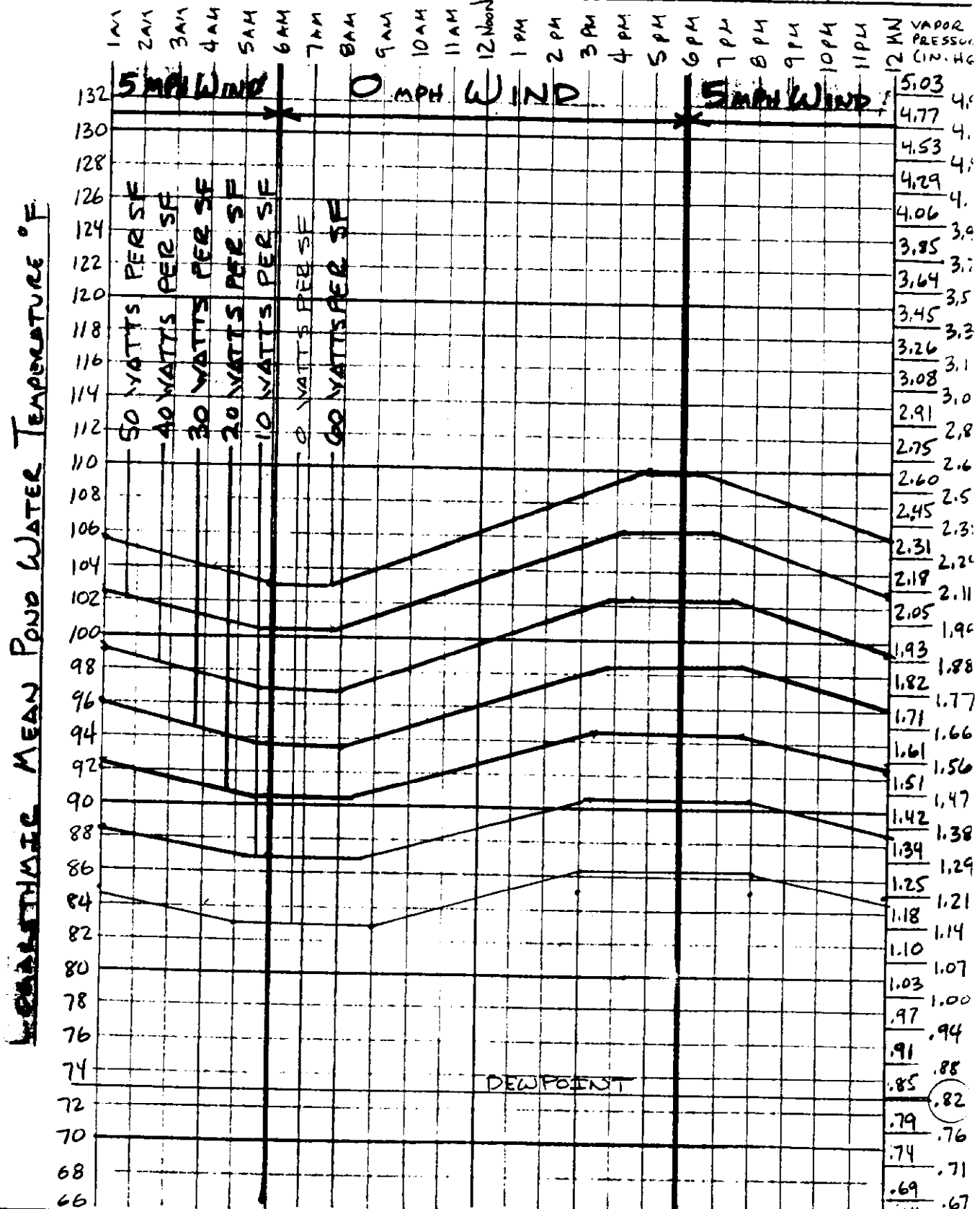
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5-0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



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FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		7'-6" Deep Pond	5A

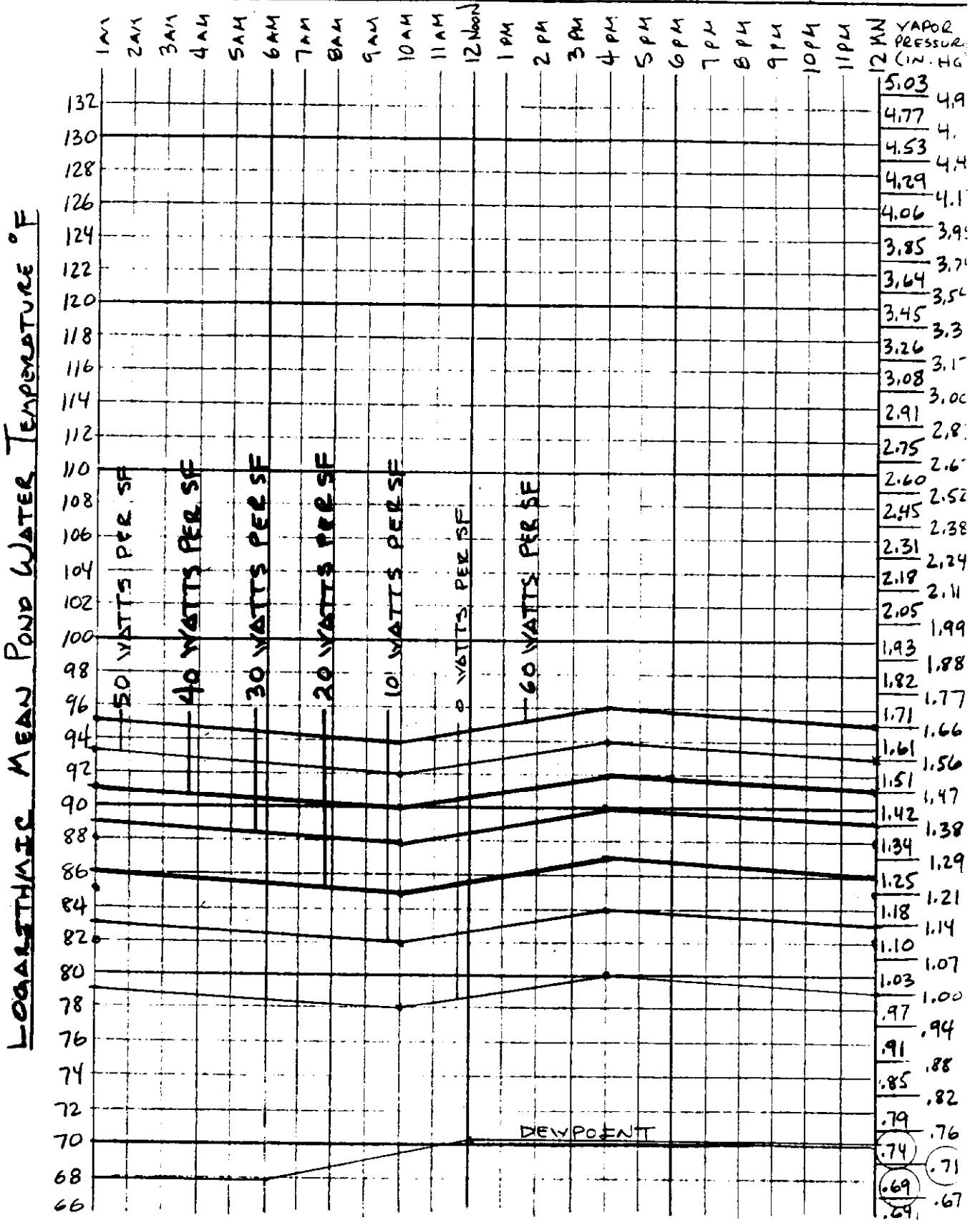
SUBJECT: Cooling Pond Performance Curves

NAME: S.F. Krstulovich

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 88 DB / 75 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		7L6" DEEP POND	5B

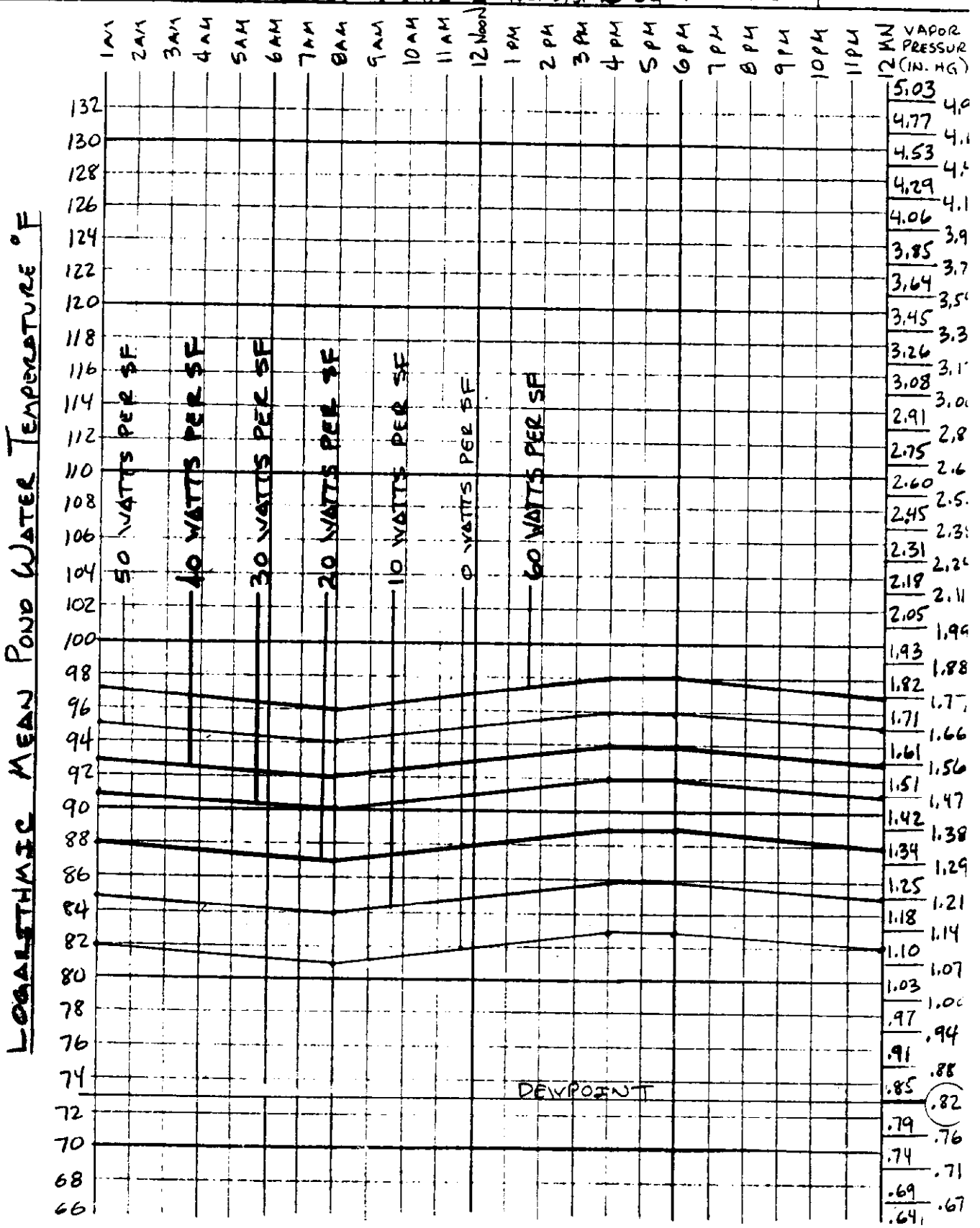
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

WIND: 5 MPH | °F OA: 95 DB / 79 WB | WATTS/SF: 0-50

DATE: 9-10-85

REVISION DATE:



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		7-6 DEEP POND	5c

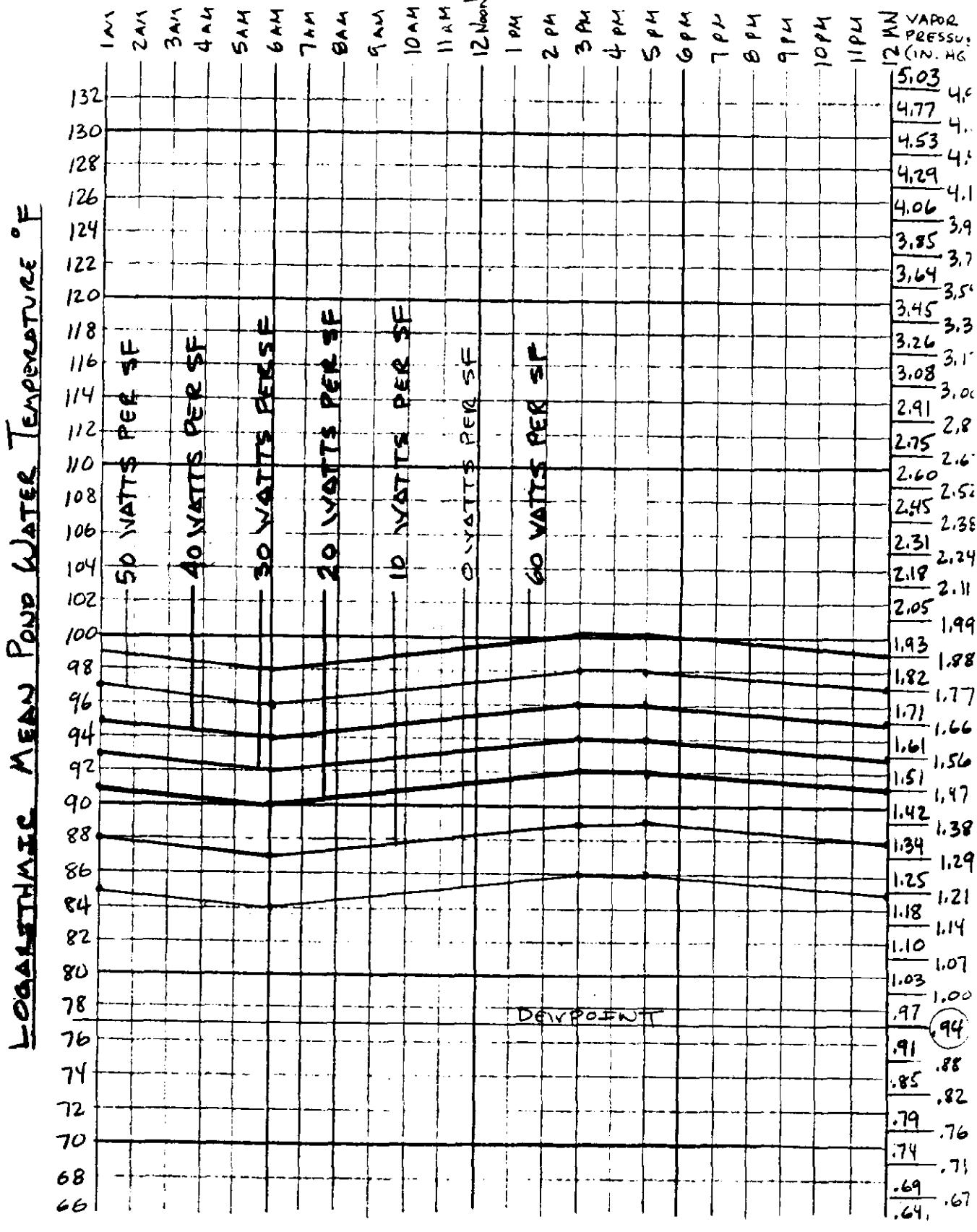
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5 MPH | OA: 107 DB / 84 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		7'-6" DEEP POND	5D

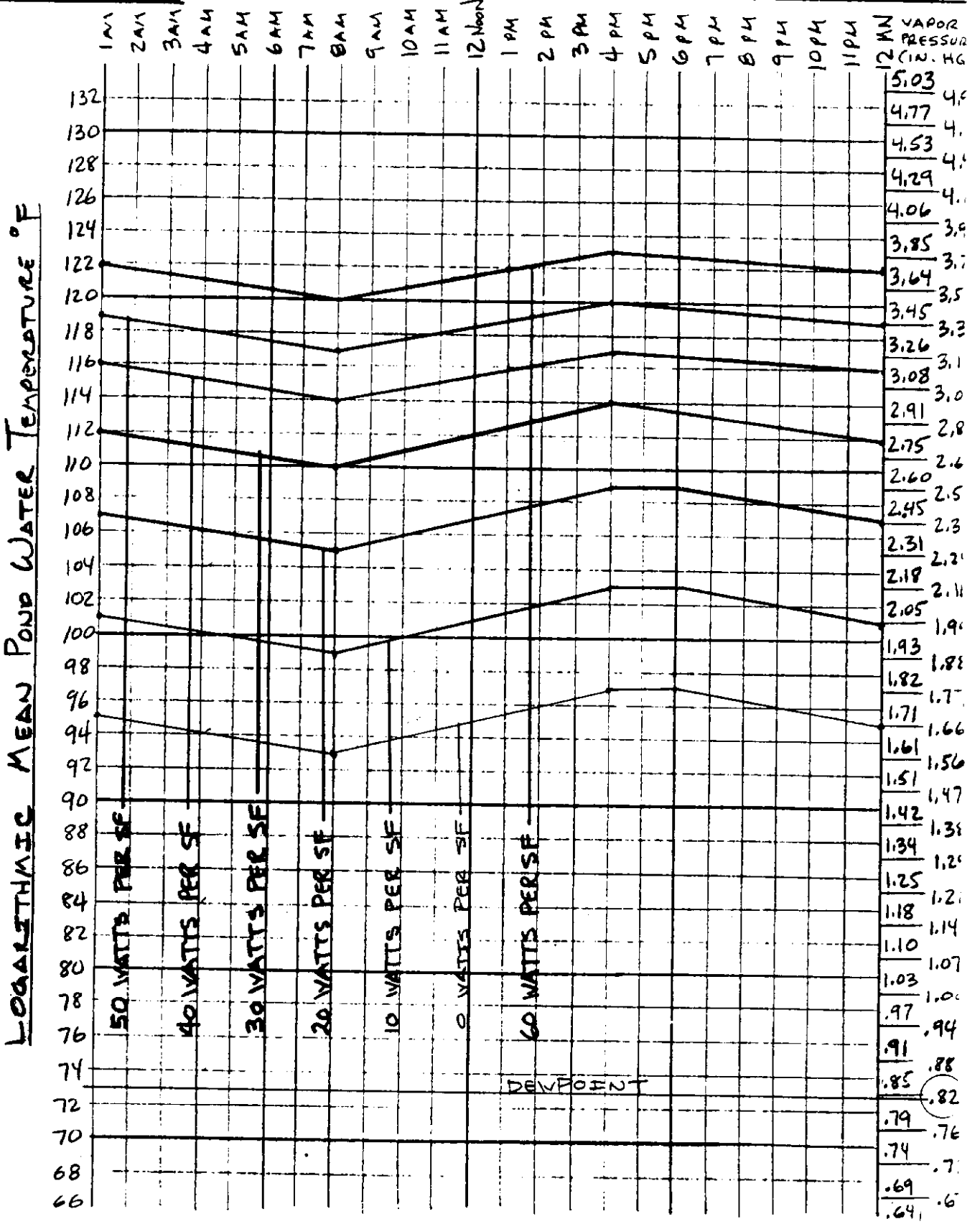
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-50



FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		7-6" DEEP POND	5E

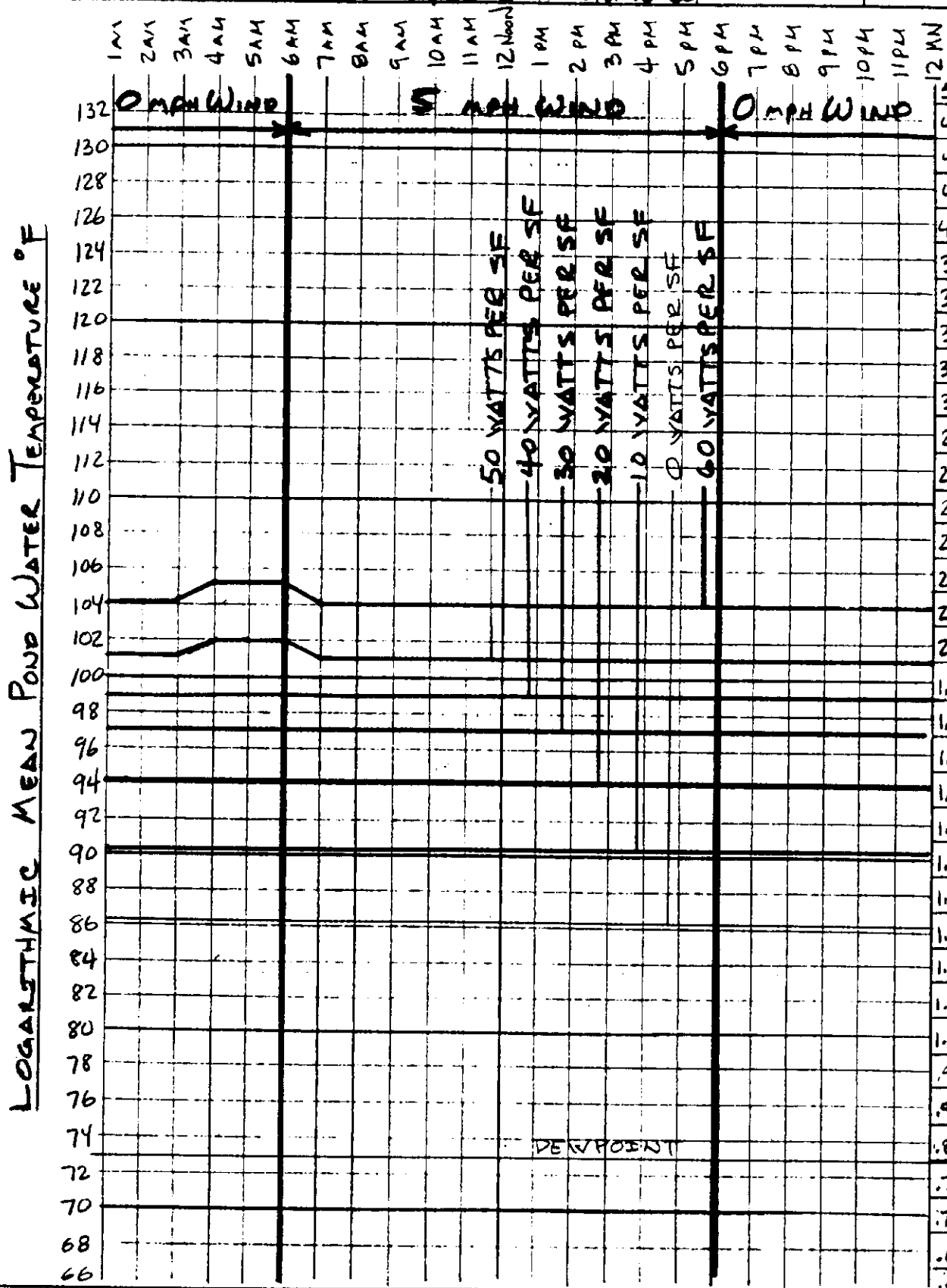
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 0-5 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



[redacted] WIND VARIABILITY EFFECTS

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		7169 DEEP POND	5 F

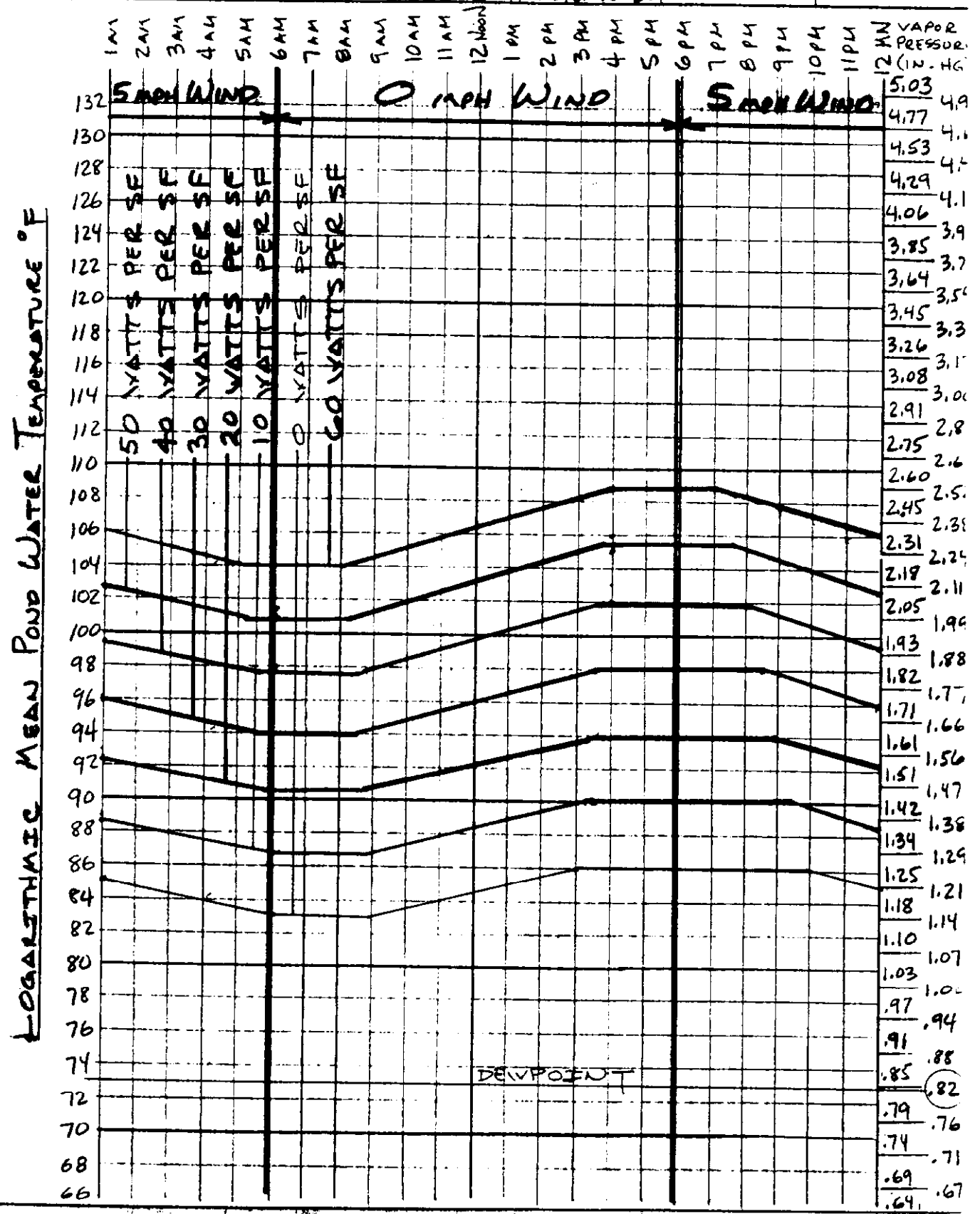
SUBJECT: COOLING POND PERFORMANCE CURVES

NAME: S.F. KRSTULOVICH

DATE: 9-10-85

REVISION DATE:

WIND: 5-0 MPH | OA: 95 DB / 79 WB | WATTS/SF: 0-60



NIGHT WIND VARIABILITY EFFECT

IV

Cooling Pond Performance

Temperature Extrapolation Formula

and

Mathematical Models

Fermilab

January 8, 1986

Memo to: J. Satti, AD/Mechanical Support

From: S. Krstulovich, Construction Engineering Services

Subject: Cooling Pond Performance ΔT Extrapolation Formula

Per your request in evaluating upcoming pond work, please find enclosed documentation pertaining to the cooling pond performance ΔT extrapolation formula in our September 17, 1985, letter to Max Palmer (pages 1 and 2 of 7 attached). This formula is an extrapolation of the familiar (LMTD) "Logarithmic-Mean Temperature Difference" formula (page 3 of 7 attached) used in evaluating heat exchanger performance which is, of course, what a cooling pond is.

Analyzing the model heat exchanger (page 4 of 7 attached), we derive equation 3 through logical expansion of equation 1 (from equations 5.34, 5.35, and 5.36 on page 3 of 7 attached), noting the thermodynamic limit that Ti_2 approaches To_2 as boundary area approaches infinity.

Referring to a typical "Cooling Pond Performance Curves" sheet (page 5 of 7 attached), we note the following equivalence in cooling pond terminology. The "0 Watts per Square Foot" curve (ZWT) represents the thermal quality of an equivalent infinite heat sink, whose To_1 and To_2 are virtually equal and whose characteristics are a derived composite of the solar, convective, radiative, and evaporative effects on the pond. The "Design Logarithmic Mean Temperature" (DLMT) is the resultant pond log mean temperature corresponding to the design pond heat loading in watts per square foot and is by definition the sum of the ZWT plus the equilibrium LMTD at the design watts per square foot loading. The numbers at the extreme right hand of the "Cooling Pond Performance Curves" are the saturated vapor pressure in inches of mercury corresponding to the temperatures on the left hand of the curve sheet. These were used in drawing up the original curves but are irrelevant to this discussion.

Analyzing the model pond (page 6 of 7 attached) we derive equation 4 by definition of DLMT and correspondence with equation 3 (on page 4 of 7 attached), noting the thermodynamic limit that Ti_2 (LWT) approaches ZWT as boundary area approaches infinity.

Finally, by permutation (pages 6 and 7 of 7), we obtain the "Cooling Pond Performance ΔT Extrapolation Formula" in equations 11 and 12.

SK/am
Encl: As Noted

cc: C. Anderson
L. Even
A. Glowacki
F. Krzich
J. Morphey
W. W. Nestander
T. Pawlak

Fermilab

September 17, 1985

Memo to: M. Palmer

From: S. Krstulovich, Construction Engineering Services

Subject: Cooling Pond Performance ΔT Extrapolation

The following example may be useful for approximating pond entering and leaving water temperatures from the cooling pond performance curves for any desired ΔT.

$$EWT = ZWT + \left[\frac{\left(\text{antilog}_e \left[\frac{\Delta T}{DLMT - ZWT} \right] \right) (\Delta T)}{\left(\text{antilog}_e \left[\frac{\Delta T}{DLMT - ZWT} \right] \right) - 1} \right]$$

$$LWT = EWT - \Delta T$$

WHERE:

ΔT = Desired Pond Water Temperature Drop
EWT = Entering Pond Water Temperature
LWT = Leaving Pond Water Temperature
DLMT = Design Logarithmic Mean Temperature at Selected Watts/SF
ZWT = Pond Temperature at Zero Watts/SF

EXAMPLE: Approximate Pond EWT and LWT for a 4'-6" Deep Pond Loaded at 20 Watts per Square Foot at Noon with Night Wind Variability Effect for a 25° ΔT

From Chart 3F: ZWT = 84
DLWT = 92

$$EWT = 84 + \left[\frac{\left(\text{antilog}_e \left[\frac{25}{92-84} \right] \right)(25)}{\left(\text{antilog}_e \left[\frac{25}{92-84} \right] \right) - 1} \right]$$

$$EWT = 110°F$$

$$LWT = (110-25) = 85°F$$

SK/am

cc: C. Anderson
L. Even
A. Glowacki
F. Krzich
J. Morphey
W. Nestander
T. Pawlak

$$U' = \frac{1}{\frac{1}{U} + \frac{x}{k}} \tag{5.33}$$

Calculated values of the overall coefficient for various types of heat exchangers are listed in Table 5.7.

Table 5.7 Calculated Values of Overall Heat Transfer Coefficient *for Various Types of Heat Exchangers*

In Btu per hr·ft²·°F

Type of Exchanger		Convection	
Heat Source	Heat Sink	Natural	Forced
Water	Water	100	1000
Water	Oil	22	222
Water	Gas	2	20
Water	Boiling liquid	167	667
Oil	Water	22	222
Oil	Oil	12	125
Oil	Gas	2	18
Oil	Boiling liquid	24	200
Gas	Water	2	20
Gas	Oil	2	18
Gas	Gas	1	10
Gas	Boiling liquid	2	20
Condensing vapor	Water	190	1330
Condensing vapor	Oil	25	236
Condensing vapor	Gas	2	20
Condensing vapor	Boiling liquid	800	800

Based on zero metal resistance and the following values for h in free and forced convection respectively. 200 and 2000 for water, 50 and 500 for oil, 2 and 20 for gas, 4000 for condensing vapor, and 4000 for boiling liquid

Mean Effective Temperature Difference

Whenever one or both of the reference temperatures in a difference vary, it is necessary to evaluate a mean temperature difference. Where the overall coefficient U is largely constant, as when a gas side resistance is controlling, the logarithmic-mean overall temperature differ[redacted]

$$\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)}, \tag{5.34}$$

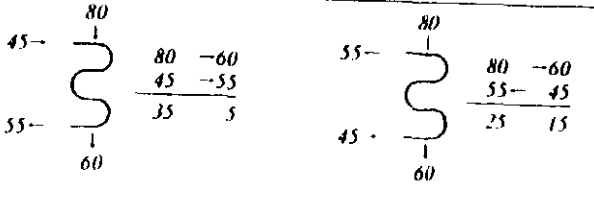
can be used. **The terminal temperature differences Δt_1 *and* Δt_2 are**

$$\Delta t_1 = t_{i1} - t_{o1} \text{ and} \tag{5.35}$$

$$\Delta t_2 = t_{i2} - t_{o2}. \tag{5.36}$$

For ease of computation the difference at terminal 1 should be the greater number and that at terminal 2, the smaller. Equation 5.34 is applicable for either parallel flow or counterflow of the two fluid streams. The difference in Δt_m for the two types of flow is best illustrated by an example.

Example 5.1 Parallel Flow MED Δt_m = and Counterflow MED Δt_m =



$$\frac{35-5}{\ln\frac{35}{5}} = \frac{30}{1.95} = 15.4 = \Delta t_m = \qquad \frac{25-15}{\ln\frac{25}{15}} = \frac{10}{.51} = 19.6 = \Delta t_m =$$

Computations can be simplified by using Figure 5.5. Additional data on MED for multi-pass and crossflow arrangements are given in the chapter on heat exchangers.

The mean temperature difference when there is no change of temperature in either fluid under steady-state conditions is

$$\Delta t_m = t_i - t_o. \tag{5.37}$$

ATTACHMENT
PAGE 3 OF 7

V

Cascade Cooling Ponds

Performance Formulas

CASCADE COOLING PONDS PERFORMANCE FORMULAS

ACTUAL POND LEAVING WATER TEMPERATURE (LWT):

$$LWT = EWT - \left[\left(EWT - ZWT \right) \left(1 - \frac{1}{1 + f_{ht}} \right)^{\alpha} \right]$$

EWT = Actual Pond Entering Water Temperature

ZWT = Maximum Daily ZWT from Criteria 3B

f_{ht} = Physical Heat Transfer Factor:

$$f_{ht} = \frac{A \times Q_{AVG}}{A_{AVG} \times Q}$$

A = Actual Pond Surface Area

A_{AVG} = Average Pond Surface Area

Q = Actual Pond Through Flow

Q_{AVG} = Average Pond Through Flow

α = Thermal Heat Transfer Exponent Factor

$$\alpha = \mathrm{Log}_{1/2} \left(\frac{EWT - ZWT - \Delta_{LT}}{EWT - ZWT} \right)$$

Δ_{LT} = Pond Leaving Water Temp. Difference Thermal Factor

$$\Delta_{LT} = \mathrm{antilog}_{\epsilon} \left(\frac{\mathrm{Log}_{\epsilon} \ (EWT - ZWT)}{\delta} \right)$$

SUBJECT: HEAT EXCHANGER MODEL

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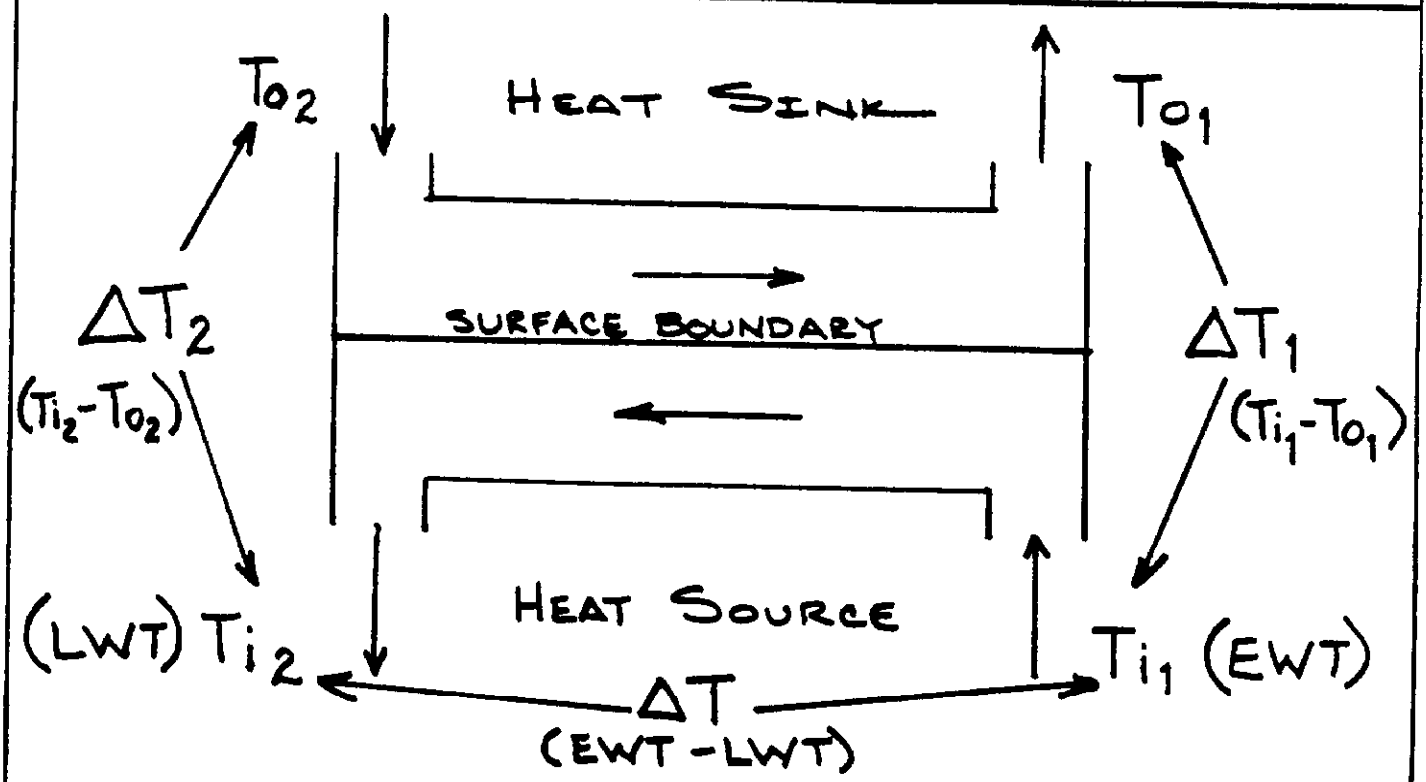
NOTE: AS SURFACE BOUNDARY APPROACHES INFINITY T_{i_2} APPROACHES T_{o_2}



LOG MEAN TEMP. DIFFERENCE (LMTD) = ΔT_m

(EQ. 1) $\therefore \quad \Delta T_m = \dfrac{\Delta T_1 - \Delta T_2}{\log_e\left(\dfrac{\Delta T_1}{\Delta T_2}\right)}$

(EQ. 2) $\therefore \quad LMTD = \dfrac{(EWT - T_{o_1}) - (LWT - T_{o_2})}{\log_e\left(\dfrac{EWT - T_{o_1}}{LWT - T_{o_2}}\right)}$

(EQ. 3) $\therefore \quad LMTD = \dfrac{(EWT - T_{o_1}) - (EWT - T_{o_2} - \Delta T)}{\log_e\left(\dfrac{EWT - T_{o_1}}{EWT - T_{o_2} - \Delta T}\right)}$

VII

Main Ring Ponds

Thermal Analysis Drawing

δ = Thermal Cooling Derivative

$$\delta = \frac{\mathrm{Log}_{\epsilon}\ (\mathrm{EWT}_{AVG} - \mathrm{ZWT})}{\mathrm{Log}_{\epsilon}\ (\mathrm{LWT}_{AVG} - \mathrm{ZWT})}$$

AVERAGE POND ENTERING WATER TEMPERATURE (EWT_{AVG}):

$$\mathrm{EWT}_{AVG} = \mathrm{ZWT} + \left[\frac{\left(\mathrm{antilog}_{\epsilon}\left[\frac{\Delta T}{\mathrm{DLMT-ZWT}}\right]\right)(\Delta T)}{\left(\mathrm{antilog}_{\epsilon}\left[\frac{\Delta T}{\mathrm{DLMT-ZWT}}\right]\right) - 1}\right]$$

DLMT = Daily Maximum DLMT from Criteria 3B

ΔT = Average Temperature Rise from Heat Loads Pond-to-Pond

GENERAL FORMULA FOR CALCULATION OF LOGARITHMS TO THE BASE 1/2 FROM COMMON LOGARITHMS (BASE 10)

$$\mathrm{Log}_{1/2}\ X = \frac{\mathrm{Log}_{10}\ X}{\mathrm{Log}_{10}\ 1/2}$$

VI

Main Ring Ponds Performance Calculations

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
			CRITERIA 3B	1/1

SUBJECT	NAME	
MAIN RING PONDS – AVERAGING PARAMETERS	S.F. KRSTULOVICH	
	DATE 31 MAY 1988	REVISION DATE

AVERAGE POND CIRCULATING FLOW: (Q_{AVG})

1000 GPM PRIMARY CW FLOW – GIVEN

AVERAGE POND TEMPERATURE RISE: (ΔT)

LCW SYSTEMS = 24 EA. × 1000 GPM × 2.9°F RISE = 69600

CRYO COMPRESSORS = 8 EA × 1200 GPM × 7.3°F RISE = 70080

RF & CDF SITES = 2 EA. × 2000 GPM × 10.2°F RISE = 40800

TOTAL = 180,480

180,480 / (24 PONDS × 1000 GPM PRIMARY CW FLOW) = 7.5 °F

AVERAGE POND SURFACE AREA: (A_{AVG})

1,178,780 TOTAL SF / 24 SECTORS = 49,116 SF

* NOTE: PONDS 24, 25 & 26 COMPRISE ONE SECTOR

AVERAGE POND EWT & LWT:

(FROM CRITERIA 3B @ 20 WATTS/SF : ZWT = 84°F, $DLMT_{MAX}$ = 90°F)

$$EWT = ZWT + \frac{\left(\text{antilog}_e\left[\frac{\Delta T}{DLMT - ZWT}\right]\right)(\Delta T)}{\left(\text{antilog}_e\left[\frac{\Delta T}{DLMT - ZWT}\right]\right) - 1} = 94.5°F$$

$$LWT = 94.5 - 7.5\,\Delta T = 87°F$$

POND AVERAGE δ DERIVATIVE:

$$\delta = \frac{\log_e(EWT - ZWT)}{\log_e(LWT - ZWT)} = 2.140314$$

AVERAGE POND HEAT LOAD (WATTS / SF):

LCW SYSTEMS = 10.2 MEGAWATTS

CRYO COMPRESSORS = 10.24 MEGAWATTS

RF & CDF SITES = 6.0 MEGAWATTS

TOTAL = 26.44 MW

26,440,000 WATTS / 1,178,780 SF = 22.4 W/SF (~20 W/SF)

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
$A_{AVG} = 49{,}116$ SF	$Q_{AVG} = 1000$ GPM	$f_{HT} = \frac{A \times Q_{AVG}}{A_{AVG} \times Q}$	1/2

SUBJECT: MAIN RING PONDS – PHYSICAL PARAMETERS

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988

REVISION DATE:

MAIN RING POND SECTION	A ACTUAL POND SURFACE AREA	Q ACTUAL POND THROUGH FLOW	FLOW DIRECTION	f_{HT} PHYSICAL HEAT TRANSFER FACTOR
POND No. 1	49380 SF	1000 GPM	CW	1.01
POND No. 2	43740 SF	1000 GPM	CW	.89
POND No. 3	43440 SF	1000 GPM	CW	.88
POND No. 4(a)	16200 SF	1000 GPM	CW	.33
POND No. 4(b)	7200 SF	200 GPM	CCW	.75
POND No. 4(c)	32760 SF	1000 GPM	CW	.67
POND No. 5	48960 SF	1000 GPM	CW	1.0
POND No. 6	43740 SF	1000 GPM	CW	.89
POND No. 7	43860 SF	3000 GPM	CW	.30
POND No. 8(a)	19800 SF	3000 GPM	CW	.13
POND No. 8(b)	8400 SF	1000 GPM	CW	.17
POND No. 8(c)	5400 SF	1400 GPM	CCW	.08
POND No. 8(d)	21600 SF	1000 GPM	CW	.44
POND No. 9	49080 SF	1000 GPM	CW	1.0
POND No. 10	43740 SF	1000 GPM	CW	.89
POND No. 11	43860 SF	1000 GPM	CW	.89
POND No. 12(a)	33600 SF	1000 GPM	CW	.68
POND No. 12(b)	22620 SF	1200 GPM*	CW	.38
POND No. 13	49380 SF	1200 GPM	CW	.84
POND No. 14	43740 SF	1200 GPM	CW	.74
POND No. 15(a)	24360 SF	1200 GPM**	CW	.41
POND No. 15(b)	19500 SF	1000 GPM	CW	.40

(CONTINUED ON SHEET 2/2)

*ASSUMES MAKEUP

**ASSUMES OVERFLOW

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE
$A_{AVG} = 49{,}116$ SF	$Q_{AVG} = 1000$ GPM	$f_{HT} = \frac{A \times Q_{AVG}}{A_{AVG} \times Q}$	2/2

SUBJECT: MAIN RING PONDS — PHYSICAL PARAMETERS

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988

REVISION DATE:

MAIN RING POND SECTION	A ACTUAL POND SURFACE AREA	Q ACTUAL POND THROUGH FLOW	FLOW DIRECTION	f_{HT} PHYSICAL HEAT TRANSFER FACTOR
POND No. 16(a)	27600 SF	1000 GPM	CW	.56
POND No. 16(b)	6000 SF	200 GPM	CCW	.60
POND No. 16(c)	22620 SF	1000 GPM	CW	.46
POND No. 17	49380 SF	1000 GPM	CW	1.01
POND No. 18	43740 SF	1000 GPM	CW	.89
POND No. 19	49140 SF	1000 GPM	CW	1.0
POND No. 20(a)	24000 SF	1000 GPM	CW	.49
POND No. 20(b)	8940 SF	1400 GPM	CCW	.13
POND No. 20(c)	18000 SF	1000 GPM	CW	.37
POND No. 21	49380 SF	1000 GPM	CW	1.01
POND No. 22	41280 SF	1000 GPM	CW	.84
POND No. 23	44760 SF	1000 GPM	CW	.91
POND No. 24(a)	20400 SF	3200 GPM	CW	.13
POND No. 24(b)	12000 SF	2000 GPM	CW	.12
POND No. 25	19800 SF	1000 GPM	CW	.40
POND No. 26	19710 SF	2200 GPM	CCW	.18

$$f_{HT} = \frac{A_{SF} \times 1000\,\text{GPM}}{49116_{SF} \times Q_{GPM}}$$

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
	ZWT = 84	δ = 2.140314	CRITERIA 3B	1/10

SUBJECT	NAME	
MAIN RING PONDS – TEMPERATURE PROFILE CALCS.	S.F. KRSTULOVICH	
	DATE	REVISION DATE
	31 MAY 1988	

PONDS No. 1: (f_{HT} = 1.01)

EWT = 89.5 + 2.9 = 92.4°F

$\text{antilog}_e(\log_e(92.4-84)/\delta) = 2.70$

$(92.4-84-2.70)/(92.4-84) = .68$

$\log_{1/2} .68 = .556$

$\Delta T = (92.4-84)(1-[1/1+1.01])^{.556} = 5.7$

$\therefore$ LWT = 92.4 − 5.7 = 86.7°F

POND No. 2: (f_{HT} = .89)

EWT = 86.7 + 2.9 = 89.6°F

$\text{antilog}_e(\log_e(89.6-84)/\delta) = 2.24$

$(89.6-84-2.24)/(89.6-84) = .60$

$\log_{1/2} .60 = .736$

$\Delta T = (89.6-84)(1-[1/1+.89])^{.736} = 3.2$

$\therefore$ LWT = 89.6 − 3.2 = 86.4°F

POND No. 3: (f_{HT} = .88)

EWT = 86.4 + 2.9 = 89.3°F

$\text{antilog}_e(\log_e(89.3-84)/\delta) = 2.18$

$(89.3-84-2.18)/(89.3-84) = .59$

$\log_{1/2} .59 = .761$

$\Delta T = (89.3-84)(1-[1/1+.88])^{.761} = 3.0$

$\therefore$ LWT = 89.3 − 3.0 = 86.3°F

POND No. 4a: (f_{HT} = .33)

EWT = 86.3 + 2.9 = 89.2°F

$\text{antilog}_e(\log_e(89.2-84)/\delta) = 2.16$

$(89.2-84-2.16)/(89.2-84) = .58$

$\log_{1/2} .58 = .785$

$\Delta T = (89.2-84)(1-[1/1+.33])^{.785} = 1.7$

$\therefore$ LWT = 89.2 − 1.7 = 87.5°F

SUBJECT: MAIN RING PONDS - TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND No. 4b: ($f_{HT} = .75$)

$EWT = 7.3 + [(200 \times 87.6) + (1000 \times 87.5)]/1200 = \underline{94.8°F}$

$\text{antilog}_e (\log_e (94.8-84)/\delta) = 3.04$

$(94.8-84-3.04)/(94.8-84) = .72$

$\log_{1/2} .72 = .473$

$\Delta T = (94.8-84)(1-[1/1+.75])^{.473} = 7.2$

$\therefore LWT = 94.8 - 7.2 = \underline{87.6°F}$

POND No. 4c: ($f_{HT} = .67$)

$EWT = (\text{SAME AS } 4b) = \underline{94.8°F}$

$\text{antilog}_e (\log_e (94.8-84)/\delta) = 3.04$

$(94.8-84-3.04)/(94.8-84) = .72$

$\log_{1/2} .72 = .473$

$\Delta T = (94.8-84)(1-[1/1+.67])^{.473} = 7.0$

$\therefore LWT = 94.8 - 7.0 = \underline{87.8°F}$

POND No. 5: ($f_{HT} = 1.0$)

$EWT = 87.8 + 2.9 = \underline{90.7°F}$

$\text{antilog}_e (\log_e (90.7-84)/\delta) = 2.43$

$(90.7-84-2.43)/(90.7-84) = .64$

$\log_{1/2} .64 = .643$

$\Delta T = (90.7-84)(1-[1/1+1.0])^{.643} = 4.3$

$\therefore LWT = 90.7 - 4.3 = \underline{86.4°F}$

POND No. 6: ($f_{HT} = .89$)

$EWT = 86.4 + 2.9 = \underline{89.3°F}$

$\text{antilog}_e (\log_e (89.3-84)/\delta) = 2.18$

$(89.3-84-2.18)/(89.3-84) = .59$

$\log_{1/2} .59 = .761$

$\Delta T = (89.3-84)(1-[1/1+.89])^{.761} = 3.0$

$\therefore LWT = 89.3 - 3.0 = \underline{86.3°F}$

SUBJECT: MAIN RING PONDS – TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND NO. 7: (f_{HT} = .30)

EWT = [(1000 × [86.3+2.9]) + (2000 × [89.1+10.2])] / 3000 = 95.9 °F

$\text{antilog}_e(\log_e(95.9-84)/S) = 3.18$

$(95.9-84-3.18)/(95.9-84) = .73$

$\log_{1/2} .73 = .454$

$\Delta T = (95.9-84)(1-[1/1+.30])^{.454} = 6.1$

∴ LWT = 95.9 − 6.1 = 89.8 °F

POND NO. 8a: (f_{HT} = .13)

EWT = [(1000 × [89.8+2.9]) + (2000 × 89.8)] / 3000 = 90.8 °F

$\text{antilog}_e(\log_e(90.8-84)/S) = 2.45$

$(90.8-84-2.45)/(90.8-84) = .64$

$\log_{1/2} .64 = .643$

$\Delta T = (90.8-84)(1-[1/1+.13])^{.643} = 1.7$

∴ LWT = 90.8 − 1.7 = 89.1 °F

POND NO. 8b: (f_{HT} = .17)

EWT = (DIRECT LWT FROM 8a) = 89.1 °F

$\text{antilog}_e(\log_e(89.1-84)/S) = 2.14$

$(89.1-84-2.14)/(89.1-84) = .58$

$\log_{1/2} .58 = .785$

$\Delta T = (89.1-84)(1-[1/1+.17])^{.785} = 1.1$

∴ LWT = 89.1 − 1.1 = 88.0 °F

POND NO. 8c: (f_{HT} = .08)

EWT = 7.3 + [(1400 × 93.2) + (1000 × 88.0)] / 2400 = 98.3 °F

$\text{antilog}_e(\log_e(98.3-84)/S) = 3.47$

$(98.3-84-3.47)/(98.3-84) = .76$

$\log_{1/2} .76 = .395$

$\Delta T = (98.3-84)(1-[1/1+.08])^{.395} = 5.1$

∴ LWT = 98.3 − 5.1 = 93.2 °F

SUBJECT: MAIN RING PONDS - TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND No. 8d: (f_{HT} = .44)

EWT = (SAME AS 8c) = 98.3°F

$\text{antilog}_e(\log_e(98.3-84)/S) = 3.47$

$(98.3-84-3.47)/(98.3-84) = .76$

$\log_{1/2} .76 = .395$

$\Delta T = (98.3-84)(1-[1/1+.44])^{.395} = 9.0$

$\therefore$ LWT = 98.3 - 9.0 = 89.3°F

POND No. 9: (f_{HT} = 1.0)

EWT = 89.3 + 2.9 = 92.2°F

$\text{antilog}_e(\log_e(92.2-84)/S) = 2.67$

$(92.2-84-2.67)/(92.2-84) = .67$

$\log_{1/2} .67 = .577$

$\Delta T = (92.2-84)(1-[1/1+1.0])^{.577} = 5.5$

$\therefore$ LWT = 92.2 - 5.5 = 86.7°F

POND No. 10: (f_{HT} = .89)

EWT = 86.7 + 2.9 = 89.6°F

$\text{antilog}_e(\log_e(89.6-84)/S) = 2.24$

$(89.6-84-2.24)/(89.6-84) = .60$

$\log_{1/2} .60 = .736$

$\Delta T = (89.6-84)(1-[1/1+.89])^{.736} = 3.2$

$\therefore$ LWT = 89.6 - 3.2 = 86.4°F

POND No. 11: (f_{HT} = .89)

EWT = 86.4 + 2.9 = 89.3°F

$\text{antilog}_e(\log_e(89.3-84)/S) = 2.18$

$(89.3-84-2.18)/(89.3-84) = .59$

$\log_{1/2} .59 = .761$

$\Delta T = (89.3-84)(1-[1/1+.89])^{.761} = 3.0$

$\therefore$ LWT = 89.3 - 3.0 = 86.3°F

SUBJECT: MAIN RING PONDS – TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND No. 12a: (f_{HT} = .68)

EWT = 86.3 + 2.9 = 89.2°F

$\text{antilog}_\epsilon(\log_\epsilon(89.2-84)/\delta) = 2.16$

$(89.2-84-2.16)/(89.2-84) = .58$

$\log_{1/2} .58 = .785$

$\Delta T = (89.2-84)(1-[1/1+.68])^{.785} = 2.6$

∴ LWT = 89.2 − 2.6 = 86.6°F

POND No. 12b: (f_{HT} = .38)

EWT = 86.6 + 7.3 = 93.9°F

$\text{antilog}_\epsilon(\log_\epsilon(93.9-84)/\delta) = 2.92$

$(93.9-84-2.92)/(93.9-84) = .71$

$\log_{1/2} .71 = .494$

$\Delta T = (93.9-84)(1-[1/1+.38])^{.494} = 5.2$

∴ LWT = 93.9 − 5.2 = 88.7°F

POND No. 13: (f_{HT} = .84)

EWT = [(1000 × (88.7 + 2.9)) + (200 × 88.7)]/1200 = 91.1°F

$\text{antilog}_\epsilon(\log_\epsilon(91.1-84)/\delta) = 2.5$

$(91.1-84-2.5)/(91.1-84) = .65$

$\log_{1/2} .65 = .621$

$\Delta T = (91.1-84)(1-[1/1+.84])^{.621} = 4.4$

∴ LWT = 91.1 − 4.4 = 86.7°F

POND No 14: (f_{HT} = .74)

EWT = [(1000 × (86.7 + 2.9)) + (200 × 86.7)]/1200 = 89.1°F

$\text{antilog}_\epsilon(\log_\epsilon(89.1-84)/\delta) = 2.14$

$(89.1-84-2.14)/(89.1-84) = .58$

$\log_{1/2} .58 = .785$

$\Delta T = (89.1-84)(1-[1/1+.74])^{.785} = 2.6$

∴ LWT = 89.1 − 2.6 = 86.5°F

SUBJECT: MAIN RING PONDS - TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

PONDS No. 15a: (f_{HT} = .41)

EWT = [(1000 x (86.5 + 2.9)) + (200 x 86.5)] / 1200 = 88.9°F

antilog_e ($\log_e$ (88.9 - 84)/δ) = 2.10

(88.9 - 84 - 2.10)/(88.9 - 84) = .57

$\log_{1/2}$ .57 = .810

$\Delta T = (88.9 - 84)(1 - [1/1 + .41])^{.810} = 1.8$

∴ LWT = 88.9 - 1.8 = 87.1°F

PONDS No. 15b: (f_{HT} = .40)

EWT = (DIRECT LWT FROM 15a) = 87.1°F

antilog_e ($\log_e$ (87.1 - 84)/δ) = 1.70

(87.1 - 84 - 1.7)/(87.1 - 84) = .45

$\log_{1/2}$ .45 = 1.15

$\Delta T = (87.1 - 84)(1 - [1/1 + .40])^{1.15} = 0.7$

∴ LWT = 87.1 - 0.7 = 86.4°F

PONDS No. 16a: (f_{HT} = .56)

EWT = 86.4 + 2.9 = 89.3°F

antilog_e ($\log_e$ (89.3 - 84)/δ) = 2.18

(89.3 - 84 - 2.18)/(89.3 - 84) = .59

$\log_{1/2}$ .59 = .761

$\Delta T = (89.3 - 84)(1 - [1/1 + .56])^{.761} = 2.4$

∴ LWT = 89.3 - 2.4 = 86.9°F

PONDS No. 16b: (f_{HT} = .60)

EWT = 7.3 + [(200 x 88.0) + (1000 x 86.9)] / 1200 = 94.4°F

antilog_e ($\log_e$ (94.4 - 84)/δ) = 2.99

(94.4 - 84 - 2.99) / (94.4 - 84) = .71

$\log_{1/2}$ .71 = .494

$\Delta T = (94.4 - 84)(1 - [1/1 + .60])^{.494} = 6.4$

∴ LWT = 94.4 - 6.4 = 88.0°F

SUBJECT: MAIN RING PONDS - TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND No. 16c: (f_{HT} = .46)

EWT = (SAME AS 16b) = 94.4°F

$\text{antilog}_e(\log_e(94.4-84)/\delta) = 2.99$

$(94.4-84-2.99)/(94.4-84) = .71$

$\log_{1/2} .71 = .494$

$\Delta T = (94.4-84)(1-[1/1+.46])^{.494} = 5.9$

$\therefore$ LWT = 94.4 - 5.9 = 88.5°F

POND No. 17: (f_{HT} = 1.01)

EWT = 88.5 + 2.9 = 91.4°F

$\text{antilog}_e(\log_e(91.4-84)/\delta) = 2.55$

$(91.4-84-2.55)/(91.4-84) = .66$

$\log_{1/2} .66 = .599$

$\Delta T = (91.4-84)(1-[1/1+1.01])^{.599} = 4.9$

$\therefore$ LWT = 91.4 - 4.9 = 86.5°F

POND No. 18: (f_{HT} = .89)

EWT = 86.5 + 2.9 = 89.4°F

$\text{antilog}_e(\log_e(89.4-84)/\delta) = 2.20$

$(89.4-84-2.20)/(89.4-84) = .59$

$\log_{1/2} .59 = .761$

$\Delta T = (89.4-84)(1-[1/1+.89])^{.761} = 3.0$

$\therefore$ LWT = 89.4 - 3.0 = 86.4°F

POND No. 19: (f_{HT} = 1.0)

EWT = 86.4 + 2.9 = 89.3°F

$\text{antilog}_e(\log_e(89.3-84)/\delta) = 2.18$

$(89.3-84-2.18)/(89.3-84) = .59$

$\log_{1/2} .59 = .761$

$\Delta T = (89.3-84)(1-[1/1+1.0])^{.761} = 3.1$

$\therefore$ LWT = 89.3 - 3.1 = 86.2°F

SUBJECT: MAIN RING PONDS — TEMPERATURE PROFILE CALCS.

NAME: S.F. KRESTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND No. 20a: (f_{HT} = .49)

EWT = 86.2 + 2.9 = 89.1°F

$\text{antilog}_e(\log_e(89.1-84)/\delta) = 2.14$

$(89.1-84-2.14)/(89.1-84) = .58$

$\log_{1/2} .58 = .785$

$\Delta T = (89.1-84)(1-[1/1+.49])^{.785} = 2.1$

∴ LWT = 89.1 − 2.1 = 87.0°F

POND No. 20b: (f_{HT} = .13)

EWT = 7.3 + [(1400 × 91.9) + (1000 × 87.0)]/2400 = 97.3°F

$\text{antilog}_e(\log_e(97.3-84)/\delta) = 3.35$

$(97.3-84-3.35)/(97.3-84) = .75$

$\log_{1/2} .75 = .415$

$\Delta T = (97.3-84)(1-[1/1+.13])^{.415} = 5.4$

∴ LWT = 97.3 − 5.4 = 91.9°F

POND No. 20c: (f_{HT} = .37)

EWT = (SAME AS FOR 20b) = 97.3°F

$\text{antilog}_e(\log_e(97.3-84)/\delta) = 3.35$

$(97.3-84-3.35)/(97.3-84) = .75$

$\log_{1/2} .75 = .415$

$\Delta T = (97.3-84)(1-[1/1+.37])^{.415} = 7.7$

∴ LWT = 97.3 − 7.7 = 89.6°F

POND No. 21: (f_{HT} = 1.01)

EWT = 89.6 + 2.9 = 92.5°F

$\text{antilog}_e(\log_e(92.5-84)/\delta) = 2.72$

$(92.5-84-2.72)/(92.5-84) = .68$

$\log_{1/2} .68 = .556$

$\Delta T = (92.5-84)(1-[1/1+1.01])^{.556} = 5.8$

∴ LWT = 92.5 − 5.8 = 86.7°F

SUBJECT: MAIN RING PONDS - TEMPERATURE PROFILE CALCS.

NAME: S.F. KRSTULOVICH

DATE: 31 MAY 1988 | REVISION DATE:

POND No. 22: (f_{HT} = .84)

EWT = 86.7 + 2.9 = 89.6°F

$\text{antilog}_e(\log_e(89.6-84)/\delta) = 2.24$

$(89.6-84-2.24)/(89.6-84) = .60$

$\log_{1/2} .60 = .736$

$\Delta T = (89.6-84)(1-[1/1+.84])^{.736} = 3.1$

$\therefore$ LWT = 89.6 − 3.1 = 86.5°F

POND No. 23: (f_{HT} = .91)

EWT = 86.5 + 2.9 = 89.4°F

$\text{antilog}_e(\log_e(89.4-84)/\delta) = 2.20$

$(89.4-84-2.20)/(89.4-84) = .59$

$\log_{1/2} .59 = .761$

$\Delta T = (89.4-84)(1-[1/1+.91])^{.761} = 3.1$

$\therefore$ LWT = 89.4 − 3.1 = 86.3°F

POND No. 24a: (f_{HT} = .13)

EWT = [(2200 × 91.4) + (1000 × 89.2)]/3200 = 90.7°F

$\text{antilog}_e(\log_e(90.7-84)/\delta) = 2.43$

$(90.7-84-2.43)/(90.7-84) = .64$

$\log_{1/2} .64 = .643$

$\Delta T = (90.7-84)(1-[1/1+.13])^{.643} = 1.7$

$\therefore$ LWT = 90.7 − 1.7 = 89.0°F

POND No. 24b: (f_{HT} = .12)

EWT = (DIRECT LWT FROM 24a) = 89.0°F

$\text{antilog}_e(\log_e(89.0-84)/\delta) = 2.12$

$(89.0-84-2.12)/(89.0-84) = .58$

$\log_{1/2} .58 = .785$

$\Delta T = (89.0-84)(1-[1/1+.12])^{.785} = 0.9$

$\therefore$ LWT = 89.0 − 0.9 = 88.1°F

POND No. 25: (f_{HT} = .40)

EWT = [(1200(89.0+7.3)) + (2000(88.1+10.2))]/3200 = 97.6°F

antilog$_e$ (log$_e$ (97.6 − 84)/δ) = 3.39

(97.6 − 84 − 3.39)/(97.6 − 84) = .75

log 1/2 .75 = .415

$\Delta T = (97.6 - 84)(1 - [1/1 + .40])^{.415} = 8.1$

∴ LWT = 97.6 − 8.1 = 89.5°F

POND No. 26: (f_{HT} = .18)

EWT = (SAME AS FOR 25) = 97.6°F

antilog$_e$ (log$_e$ (97.6 − 84)/δ) = 3.39

(97.6 − 84 − 3.39)/(97.6 − 84) = .75

log 1/2 .75 = .415

$\Delta T = (97.6 - 84)(1 - [1/1 + .18])^{.415} = 6.2$

∴ LWT = 97.6 − 6.2 = 91.4°F