HARZA-EBASCO
Susitna Joint Venture
Document Number

3058

Please Return To
DOCUMENT CONTROL

J.H.Thrall

SUSITNA JOINT VENTURE

ANDUM

Office

DATE August 22, 1984

TO EJG, JHT, WEL, AZ, FGD

NUMBER

FROM H.W. Coleman

SUBJECT Susitna Project
Fixed Cone Vales
N_2 Supersaturation

References:

1. Allis-Chalmers Bulletin - "Howell-Bunger" Valves.

2. Elder, Rex A., and Dougherty, Gale B., "Characteristics of Fixed-Dispersion Cone Valves", Paper No. 2567, Transactions, ASCE.

3. Chen, T.F., and Davis, John R., "Disintegration of a Turbulent Water Jet", Journal of the Hydraulics Division, ASCE, HY1, January 1964.

4. United States Department of Interior, "Air-Water Flow in Hydraulic Structures", Engineering Monograph No. 41, 1980.

5. Johnson, Geoffrey, "The Effect of Entrained Air on the Scouring Capacity of Water Jets", Proceedings of the 12th Congress of IAHR, Ft. Collins, CO, 1967, Vol. 3.

6. Acres Office Memorandum, "Susitna Hydroelectric Project, Nitrogen Supersaturation Studies", G. Krishnan, September 13, 1982.

Background

The fixed cone valves have been included in the Watana and Devil Canyon layouts in order to mitigate possible nitrogen supersaturation in the river downstream for releases up to the 50 year flood event. The ACRES computation which supported the effectiveness of the cone valves for this purpose has several inconsistencies which would probably not stand up under close inspection. For this reason, JHT asked me to update the computation using defendable computations based on relevant references.

The resulting computations and references are included in Appendices A and B.

HARZA-EBASCO SUSITNA JOINT VENTURE

MEMORANDUM

LOCATION Chicago Office

DATE August 22, 1984

TO EJG, JHT, WEL, AZ, FGD

NUMBER

FROM H.W. Coleman

Page Two

SUBJECT Susitna Project
Fixed Cone Vales
N_2 Supersaturation

Operating Conditions

	Watana	Devil Canyon
HW	2185	1455
TW	1455	880
El. of Valves	1560	1050 (Upper) 930 (Lower)
Number, Size Valve	6 @ 78"	4 @ 102" (Upper) 3 @ 90" (Lower)
Design Discharge (per valve)	4000 cfs	5800 cfs (Upper) 5100 cfs (Lower)
Power Flow	0-7000 cfs	0-7000 cfs

Watana Reservoir and power flow assumed to be 100% saturated with N_2.

Computations

The following computations were made:

1. Theoretical trajectories of various portions of the valve discharge.
2. Air entrainment of jet.
3. Possible disintegration of jet before reaching tailwater.
4. Jet penetration of tailwater with and without effect of air entrainment.
5. Expected N_2 supersaturation with and without powerhouse operating.

Computations are included in Appendix A.

HARZA-EBASCO SUSITNA JOINT VENTURE

MEMORANDUM

LOCATION Chicago Office

DATE August 22, 1984

TO EJG, JHT, WEL, AZ, FGD

NUMBER

FROM H.W. Coleman

SUBJECT Susitna Project
Fixed Cone Vales
N_2 Supersaturation

__Results__

__Watana Only__ (1996-2001): HW 2185
TW 1455

	N2 Supersaturation
Range of N_2 Supersaturation in impact zone	0-17%
Fully mixed supersaturation	
1 Valve operating	4.2%
6 Valves operating	4.2%
6 Valves + Powerhouse	3.2%
1 Valve + Powerhouse	1.5%

Devil Canyon (2002-2020)		(with Watana)
Range of N_2 Supersaturation in impact zone	0-26%	1.5%-30%
Fully mixed supersaturation		
1 Valve operating	0% (Upper)	4.2%
	6.1% (Lower)	10.3%
7 Valves operating	2.4%	6.6%
7 Valves + Powerhouse	2.1%	5.3%
1 Valve + Powerhouse	0% (Upper)	1.5%
	2.6% (Lower)	4.1%

HARZA-EBASCO SUSITNA JOINT VENTURE

MEMORANDUM

LOCATION Chicago Office

DATE August 22, 1984

TO ~~EJG, JHT, WEL, AZ, PGD~~

NUMBER

FROM H.W. Coleman

SUBJECT Susitna Project
Fixed Cone Vales
N_2 Supersaturation

Conclusions

1. Final mixed supersaturation levels when Watana operating alone from 1996 thru 2001 are expected to be in the range of 1.5-4.2%.

2. After Devil Canyon comes on line in 2002, particularly in the first few years when there is excess generating capacity, it is expected that cone valves will occasionally discharge simultaneously at both Watana and Devil Canyon. In this case, it is assumed that N_2 levels produced by Watana discharge will not be removed in the Devil Canyon Reservoir. Therefore, the supersaturation effects at the two dams will be cumulative. The resulting levels of N_2 supersaturation are expected to be somewhat higher in the Devil Canyon tailrace than at Watana, ranging from 1.5% to 6.6%. Note that if one of the lower level valves at Devil Canyon is operating alone, N_2 supersaturation levels can be as high as 10.3%. It is therefore recommended that the upper level valves at Devil Canyon always be used first if possible.

3. These computations indicate that the fixed cone valves at Watana and Devil Canyon are sufficient to limit N_2 supersaturation in the river to levels well below the 10% limit, for all operations without the spillways.

H.W. Coleman
H.W. Coleman

HWC/mmg

DISCHARGE EQN FOR HOWELL-BUNGER VALVE

@ 80% OF SLEEVE TRAVEL:

$K_{80\%} = 5.039$
$K_{100\%} = 5.354$

} ALLIS CHALMERS BULLETIN "HOWELL-BUNGER VALVES" (REF 1.)

$$C = \left(\frac{5.039}{5.354}\right)(0.85) = 0.80$$

$$Q = KD^2\sqrt{H} = (5.039)\left(\frac{78}{12}\right)^2\sqrt{575}$$

Q = 5105 cfs (per valve)

Valves may be somewhat oversized for 4000 cfs.

Watana

HW = 2185

℄ valves = 1560

Gross H = 625'

Losses ~ 50' (With 6 valves @ 4000 cfs)

Net H = 575'±

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT Watana - Cone Valves	FILE NO. 563-[illegible]
	COMPUTED GEB CHECKED HWC	DATE 5/2[illegible]
		PAGE 2 OF 13 PAGES

FLOW DISPERSION ANGLE WHEN SLEEVE IS

OPEN 0.45D (80% OPEN):-

$\measuredangle \cong 42°$ - FROM: DISCUSSION BY T.T. SIAO "CHARACTERISTICS OF FIXED-DISPERSION CONE VALVES"; ELDER, R.A., DOUGHERTY, G.B., ASCE TRANSACTIONS, PAPER 3567 (REFERENCE 2.)

TRAJECTORY EQUATION FROM "DESIGN OF SMALL DAMS":

$$y = \pm x \tan\theta - \frac{x^2}{K[4h_n \cos^2\theta]}$$

WHERE: $\theta = 42°$
$h_n = 575$
$k = 0.9$ (Air Resistance)

$$y = \pm 0.900x - x^2/1143 \quad \text{(Watana)}$$

SOLVE FOR JET IMPACT ∡ AND UNIT DIS[illegible]E:

. Watana —— Lower Nappe

$$y = -105 = -0.900x - x^2/1143$$

$x \cong 105$ ft (Lower Nappe)

$$\frac{dy}{dx} = -0.900 - \frac{2x}{1143} = -1.084$$

$$\measuredangle_{IMPACT} = \text{ARCTAN}(-1.084) = 47.3°$$

APPROXIMATE DISTANCE FROM VALVE ℄

TO TAILWATER IMPACT POINT $= \sqrt{(105)^2 + (105)^2}$

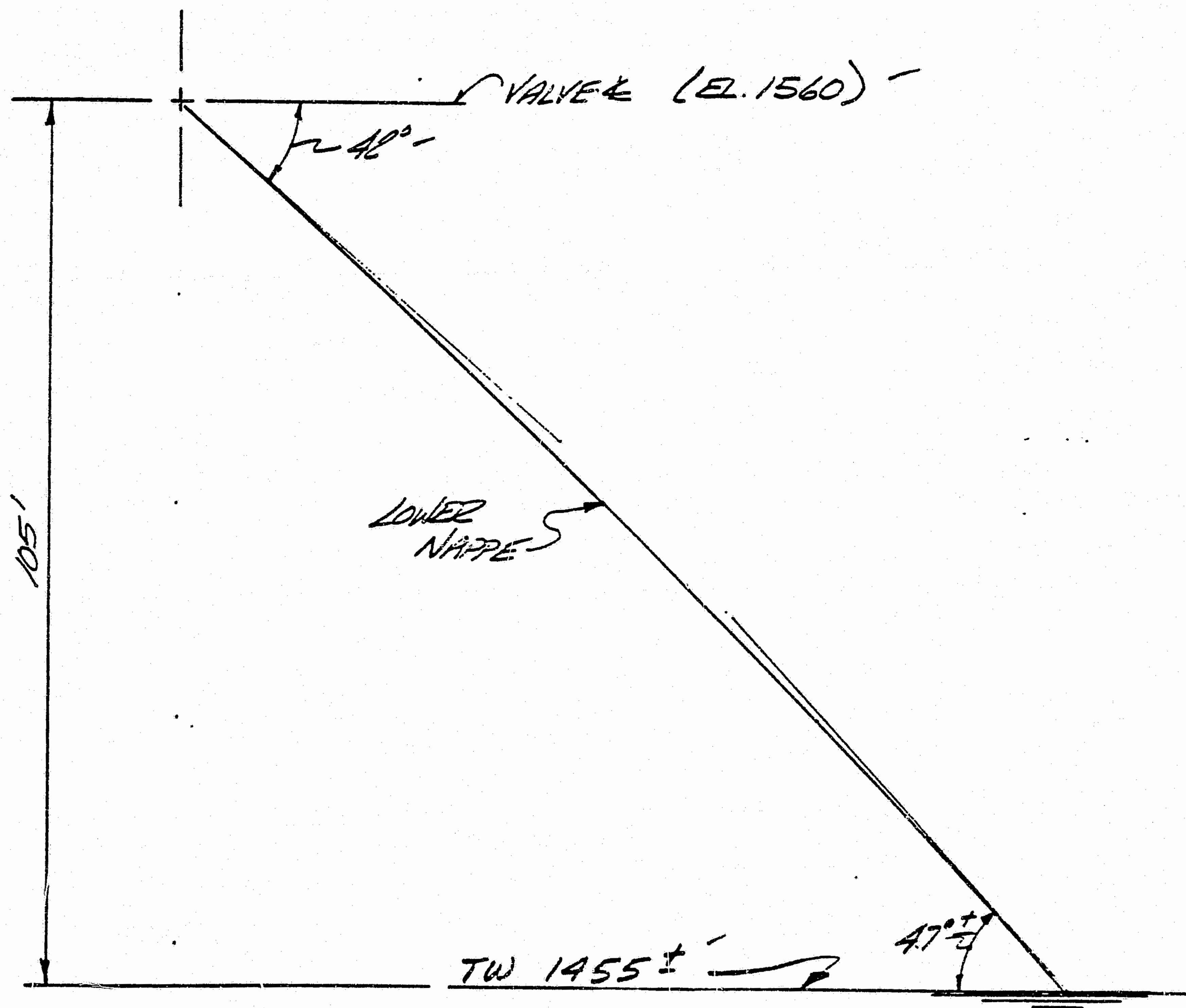
$\cong 149$ ft

PLOT TRAJECTORY OF LOWER NAPPE:

x, ft	y, ft
25	-23.0
50	-47.2
75	-72.4
100	-98.7
105	-104.1
106	-105

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT Watana - Cone Valves	FILE NO. 1563-KS
	COMPUTED GEB CHECKED HWT	DATE 5/29/84
		PAGE 4 OF 13 PAGES

LOWER NAPPE



AVERAGE SPREAD ∢ = 45°

JET RADIUS @ IMPACT = 149/√2 = 105.4 ft

LOWER NAPPE

UNIT q @ CONE:

Cone diameter = 78/12 = 6.5 ft

Cone circumference = πD = 20.42 ft

q_c = 4000 cfs / 20.42 ft ≅ 196 cfs/ft (USE 4000 cfs DESIGN DISCHARGE)

q_i = 4000 cfs / ((π)(2)(105)) = 6.06 cfs/ft

DETERMINE PLUNGE DEPTH: (DESIGN OF SMALL DAMS P.)

$y = 1.32\, H^{0.225}\, \underline{q}^{0.54} = (1.32)(575 + 105)^{0.225}(6.06)^{0.54}$

= 15.2 ft (along tangent)

= 11.1 ft (vertical) ← Plunge without consideration of aerated jet.

APPROX. PERCENT SATURATION = 100% + (3%)(11) = 133% (w/o JET AERATION)

UPPER NAPPE TRAJECTORY:

$y = 0.90x - x^2/1143$ (UPPER NAPPE)

$y' = 0.90 - \dfrac{2x}{1143}$

At $y' = 0$: $2x = 0.9 \times 1143$

$x = \underline{514}^{\pm}$ ($y = 231.^{\pm}$)

Upper Nappe -

x	$.90x$	$x^2/1143$	y	ΔL	
100	90	9	81.	129.	
200	180	35	145.	119.	
300	270	79	191.	110.	
400	360	140	220.	104.	
514	462	231	231.	115.	577
600	540	315	225.	86.	
700	630	429	201.	103.	
800	720	560	160.	108.	
900	810	709	101.	116.	
1000	900	875	25.	126.	
1028	925	925	0.	38.	
1100	990	1059	-69.	100.	
~~1150~~	1035	1157	-122.	73.	
1135	1022.	1127	-105	50	$\Sigma \Delta L = 1304.$

Impact Angle $\cong \tan^{-1}\left[0.90 - \frac{2 \times 1135}{1143}\right] = -47.4°$

DETERMINE IF UPPER NAPPE DISINTEGRATES BEFORE IMPACT WITH TW:

Valve exit $V = \sqrt{2gH} = \sqrt{2g(575)} = \underline{192}$ ft/s

Jet Thickness $\cong \dfrac{4000}{192 \times \pi \times 6.5} = \underline{1.02'}$

From "DISINTEGRATION OF A TURBULENT WATER JET," T. F. Chen and J. R. Davis, ASCE Hydraulics Journal, Jan. 1964 (Ref. 3).

Weber Number, $W = V \Big/ \sqrt{\sigma/\rho D}$

ρ = density of water = 1.94
σ = surface tension of water = .005
} T = 50°-60°F

V, D = velocity and thickness of exit jet

$$W = 192 \Big/ \sqrt{.005 / 1.94 \times 1.02} = \underline{3820.}$$

$$R = \frac{VD}{\nu} = \frac{192\,(1.02)}{1.4 \times 10^{-5}} = \underline{14 \times 10^6}$$

$$\bar{L}/D = 1.15\,W + 30 = 1.15\,(3820) + 30 = 4423$$

$$\bar{L} = \underline{4511'} > 1304' \text{ (Upper Nappe Length)}$$

Previous computation indicates the jet upper nappe would not break up. However, the experimental equation is based on a uniform q along the trajectory, which is not true in this case:

Therefore, check for break-up at apex of trajectory:

At apex, $x = 514'$, $\Sigma \Delta L = 577'$

$$q_1 = \frac{149}{577} \times 6.06 = 1.56 \text{ cfs/ft.}$$

$$V_1 = \sqrt{2g(575 - 231)} = 149 \text{ ft/s}$$

$$D_1 = \frac{1.56}{149} = .01'$$

$$W = 149 \Big/ \sqrt{.005/_{1.94 \times .01}} = 293$$

$$\bar{L}/D = 1.15(293) + 30 = 367$$

$$\bar{L} = 367 \times .01 = \underline{3.67'}$$

∴ Upper nappe will break-up long before impact and no plunge will occur.

Check Lower Nappe for break-up before impact

At mid-point of trajectory:

$$q = \frac{4000}{2\pi \times 50^{\pm}} = 12.7 \text{ cfs/ft}$$

$$V = \sqrt{2g(575 + 50)} = \underline{201.} \text{ ft/s}$$

$$D = \frac{12.7}{201} = .063'$$

$$W = 201 \Big/ \sqrt{.005 / 1.94 \times .063} = \underline{999.}$$

$$\bar{L}/D = 1.15(999) + 30 = \underline{1173.}$$

$$\bar{L} = 1173 \times .063 = \underline{74'}$$

Actual distance ~ 75'

Jet probably breaks up before impact, but not certain. Assume no break-up for lower nappe.

∴ Super-saturation will occur at lower nappe impact.

HARZA-EBASCO
SUSITNA JOINT VENTURE
SUBJECT Watana-
Cone Valv...

HARZA-EBASCO
SUSITNA JOINT VENTURE

SUBJECT Watana- Cone Valves
COMPUTED JEB CHECKED HWC
FILE NO. 1563.142
DATE 6/4/84

Estimate jet air entrainment:

1. From aeration ramp test results:

$q_a = C L V$, C = experimental coefficient $\sim .03$

V = jet velocity

L = trajectory length

Lower Nappe: $q_a = .03(150)(192) = 864$ cfs/ft.

At valve: $\frac{q_a}{q_w} = \frac{864}{196} = 441\%$

At impact: $\frac{q_a}{q_w} = \frac{864}{6.06} = \ggg 1000\%$

$\therefore$ Jet will be fully air entrained at impact.

2. Check based on H-B valve tests (Ref 4):

For unhooded valve, $\frac{\rho_{in}}{\gamma} \approx 0$

$\therefore Q_a/Q_w > 3.0$ - Confirms fully aerated.

Ref. 4: Air-Water Flow in Hydraulic Structures, H.T. Falvey, USBR Monograph 41.

Estimate jet air entrainment:

1. From aeration ramp test results:

$$q_a = CLV, \quad C = \text{experimental coefficient} \sim .03$$

V = jet velocity

L = trajectory length

Lower Nappe: $q_a = .03(150)(192) = 864 \text{ cfs/ft.}$

At valve: $\frac{q_a}{q_w} = \frac{864}{196} = 441\%$

At impact: $\frac{q_a}{q_w} = \frac{864}{6.06} = >>> 1000\%$

∴ Jet will be fully air entrained at impact.

2. Check based on H-B valve tests (Ref 4):

For unhooded valve, $\frac{p_{in}}{\gamma} \approx 0$

∴ $Q_a/Q_w > 3.0$ – Confirms fully aerated.

Ref. 4: Air-Water Flow in Hydraulic Structures, H.T. Falvey, USBR Monograph 41.

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT Watana - Cone Valves	FILE NO. 1563.142
	COMPUTED JEB CHECKED HWC	DATE 6/4/84
		PAGE 11 OF 13 PAGES

Determine effect of entrained air on jet plunge:

From Ref. 5: The Effect of Entrained Air on the Scouring Capacity of Water Jets, G. Johnson, IAHR Proceedings of 12th Conference, 1967.

Fig 3 indicates that if a jet is 50% aerated, $\frac{q_a}{q_a + q_w} \geq 50\%$, then plunge will be reduced about 50%.

∴ Lower Nappe Vertical Plunge computed for solid water jet, (11.1'), will be reduced to only 5.6'.

Resulting super-saturation for Lower Nappe will be only $3 \times 5.6 = 16.8\%$

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT Watana - Cone Valves	FILE NO. 1563.192
	COMPUTED JEB CHECKED KWC	DATE 6/4/84 PAGE 12 OF 13 PAGES

Check trajectory at valve spring-line:

Exit angle = 0° with horizontal.

$$y = -\frac{x^2}{2070}$$

$y = -105$

$x = \underline{466}$

$$y' = -\frac{2x}{2070}$$

$$= \frac{-2(466)}{2070} = -0.45$$

Impact Angle = $\underline{-24.2°}$

Check for jet dispersion near mid-length of trajectory: say $L \sim 200'$.

$V \sim 200$ ft/sec.

$$q \sim \frac{149}{200} \times 6.06 = 4.5 \text{ cfs/ft.}$$

$$D = \frac{4.5}{200} = .0225'$$

$$W = 200 / \sqrt{.005 / 1.94 \times .0225} = 591$$

$$\bar{L}/D = 1.15(591) + 30 = 710$$

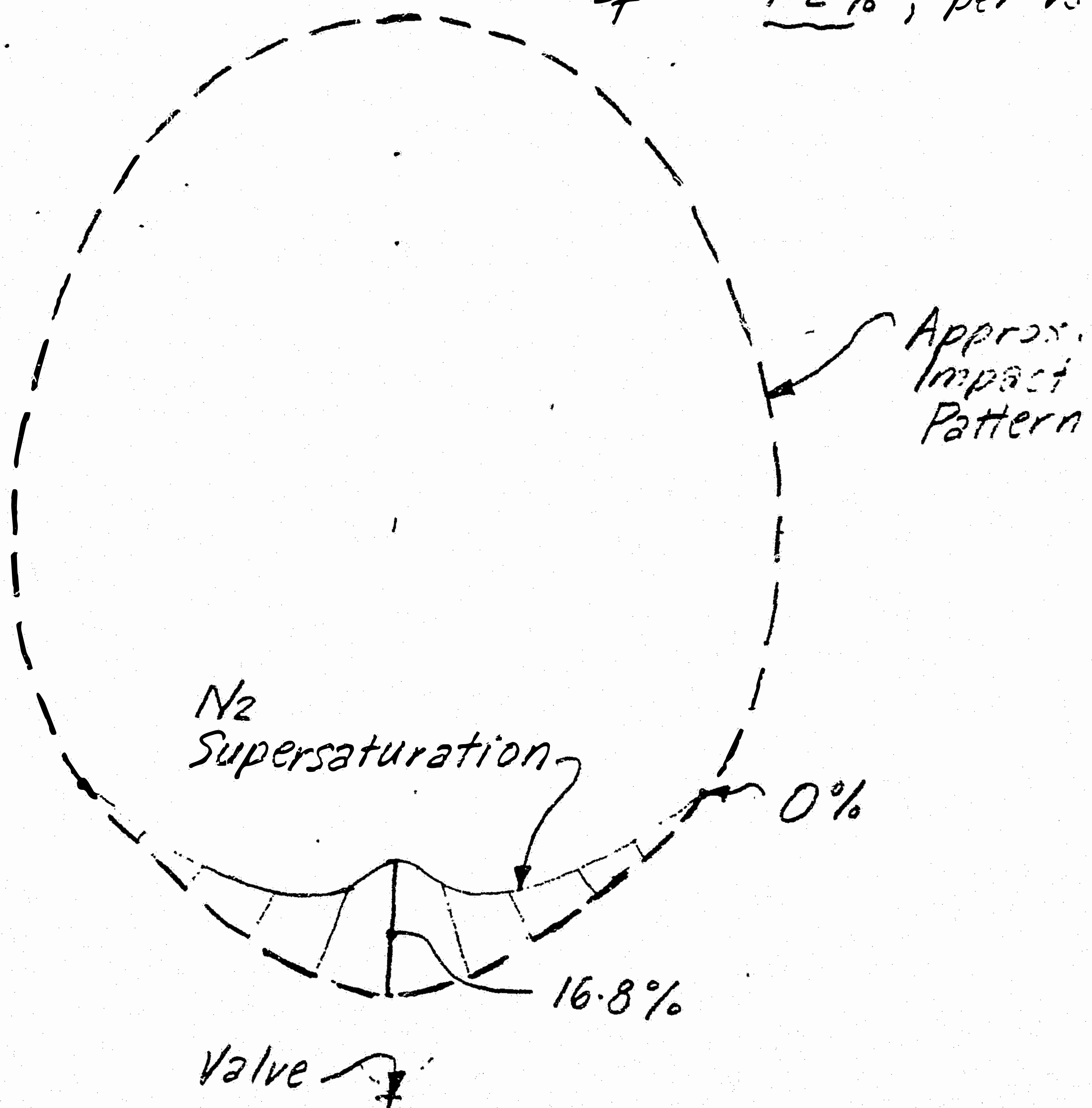
$\bar{L} = 710 \times .0225 = \underline{16.'}$ ∴ Upper half of jet will disintegrate.

Upper half of jet will disintegrate and will not plunge ∴ N_2 supersaturation will = 0.

Assume lower half N_2 supersaturation varies from max. of 16.8 % at lower nappe to 0% at spring-line.

$$\text{Final mixed super-saturation} = \frac{\frac{16.8+0}{2} + 0}{2}$$

S_f = 4.2%, per valve



$$\text{With Powerhouse: } N_2 = \frac{6 \times 4.2 \times 4000 + 7000 \times 0}{31{,}000} = 3.2\%$$

Cone Valves - Determine N_2 Supersaturation.

Normal Max. HW = 1455.

℄ Lower Level Valves = 930.

Gross H = 525.'

Design Discharge = 5100 cfs

Valve ϕ = 90", A = 44.2 ft^2

$$Q = C A \sqrt{2gH}$$

$$5100 = C(44.2)\sqrt{2g(525)}$$

$C = 0.63$ (Full Open $C \sim 0.85$) Ref. 1

Assume 0.2 H loss in conduit:

Net $H = 0.8(525) = 420$

$$5100 = C'(44.2)\sqrt{2g(420)}$$

$C' = 0.70$ [Valve Op'g ~ 63%]

Lower Nappe Trajectory:

Exit Angle $\sim \pm 42°$ (Ref. 2)

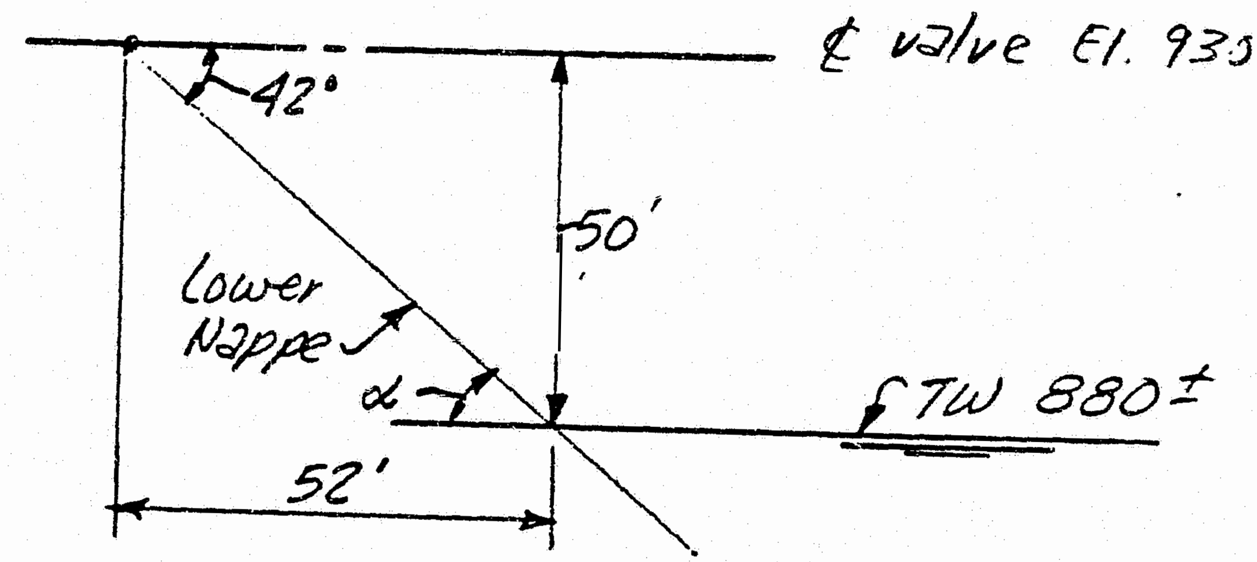
$$y = -x \tan\theta - x^2/4KH\cos^2\theta$$ (Small Dams)

$H = 420'$
$K = 0.9$ (Air Resistance)
$\theta = \pm 42°$

$$y = -x \tan 42° - x^2/4(0.9)(420)\cos^2 42°$$

$$y = -0.90x - x^2/835$$

x	$-.90x$	$-x^2/835$	$-y$
25	22.5	0.7	23.2
50	45.0	3.0	48.
52	46.8	3.2	50.



Unit q at valve:

$$q_v = \frac{5100}{\pi(7.5)} = 216.5 \text{ cfs/ft}$$

At Lower Nappe Impact:

$$q_i = \frac{5100}{\pi(100)} = 16.2 \text{ cfs/ft}$$

Plunge Depth (Without Aeration):

$$d_s = 1.32\, q^{0.54} H^{.225} \quad \text{(Small Dams)}$$

$$= 1.32\,(16.2)^{0.54}\,(420+50)^{0.225}$$

$d_s = 23.7'$ (Along tangent)

$y_s = d_s \sin\alpha$ (Vertical component)

$$y' = -0.90 - 2x/835$$

$$y' = -.90 - x/417.5$$

At $x = 52$ $\quad y' = -.90 - .12 = -1.02$

$$\alpha = \tan^{-1} -1.02$$

$$\alpha = -45.5^\circ$$

$y_s = 23.7 \sin -45.5 = 16.9'$ (Vertical component)

Lower Nappe Plunge:

Check for Jet Break-up at mid-length:

$$W = V / \sqrt{\sigma / \rho D} \quad \text{(Ref. 3)}$$

W = Weber No.
ρ = density of water
σ = surface tension of H_2O
V, D = velocity, thickness of jet

$$V_{T.F.} = \sqrt{2g(420 + 25)} = 169 \text{ ft/s.}$$

$$D_{m1} = q/V, \quad q = \frac{5100}{\pi(50)} = 32.5 \text{ cfs/ft.}$$

$$D_{m1} = 32.5/169. = 0.19'$$

$$W_{m1} = 169 \Big/ \sqrt{\frac{.005}{1.94 \times .19}} = 1451.$$

$$\bar{L}/D = 1.15\,W + 30 = 1.15(1451) + 30 = 1699$$

$$\bar{L} = 1699 \times .19 = \underline{323.'}$$ (Lower Nappe will not break up)

Lower Nappe Plunge:

Check effect of air-entrainment:

1. $q_a = CVL = .03\left(\sqrt{2g(420)}\right)(51\sqrt{2}^{\pm})$

$$q_a = 356 \text{ cfs/ft}$$

At Valve $q_a/q_v = \frac{356}{216.5} = 164\%$

At Impact $q_a/q_v = \frac{356}{16.2} = 2200\%^{\pm}$

2. From H-B tests (Ref. 4):

For unhooded valve, $\frac{P_{in}}{\gamma} = 0$

$Q_a/Q_w > 3.0$

∴ Jet fully entrained at impact.

From Ref. 5, if jet is at least 50% air, then penetration in TW will be reduced by 50%.

∴ Lower Nappe Plunge $= .5 \times 16.9 = 8.5'$

N_2 Supersaturation $= 8.5' \times 3\%/\text{ft} = 25.5\%$

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT: Devil Canyon – Cone Valves	FILE NO. 1563.142
	COMPUTED: Hwc CHECKED:	DATE 20 Aug 84
		PAGE 6 OF 11 PAGES

Upper Nappe –

Trajectory: $y = x \tan 42° - x^2 / 4(.9)(420)\cos^2 42°$

$$y = .90x - x^2/835$$

Apex: $y' = 0 = .90 - 2x/835$

$$x = \underline{376'}$$

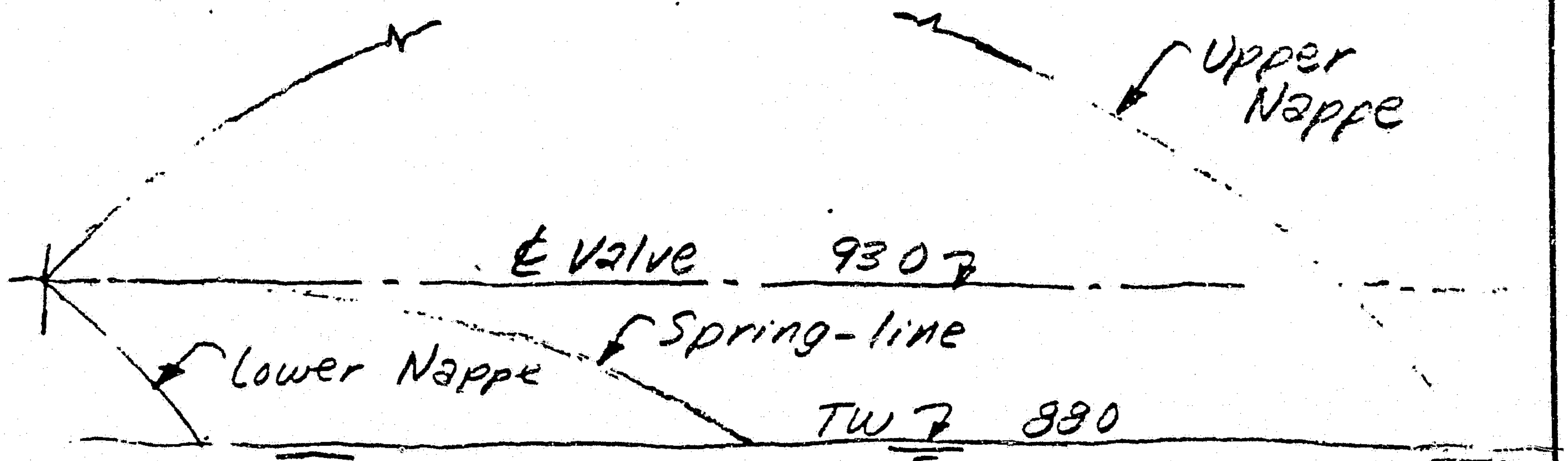
At $x = 752'$, $y' = -0.9$ (– 42°)

Find Entry Angle

x	$.90x$	$x^2/835$	y
800	720	766	–46
804	724	774	–50 ✓

$$y' = .90 - x/417.5 = .90 - 804/417.5$$

α = – $\underline{45.7°}$ (Upper Nappe Entry ∠)



Upper Nappe ~

Check for jet break-up at apex of trajectory

$x = 376'$

$y = 169'$

$S \approx \sqrt{(376)^2 + (169)^2} = 412.$

$q_{ap} = \frac{\sqrt{2}\,(51)}{412} \times 16.2 = 2.84 \text{ cfs/ft.}$

$V_{ap} = \sqrt{2g(420-169)} = 127 \text{ ft/s}$

$D_{ap} = q_{ap}/V_{ap} = 2.84/127 = .02'$

$W = 127 \Big/ \sqrt{.005/1.94 \times .02} = 354$

$L/D = 1.15(354) + 30 = 437.$

$L = 437 \times .02 = \underline{8.7'}$

Upper Nappe will break-up long before impact. No plunge will occur.

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT: Devil Canyon - Cone Valves	FILE NO. 1563.1[illegible]
	COMPUTED: HWC CHECKED:	DATE: 21 Aug 84
		PAGE 8 OF 11 PAGES

Check trajectory at valve spring-line:

Exit $\measuredangle = 0°$

$$y = -x^2/4 \times .9 \times 420 = -x^2/1512$$

$$y = -50$$

$$x = \sqrt{1512 \times 50} = \underline{275.'}$$

Check for jet break-up at mid-length

$$L \approx \frac{1}{2}\sqrt{(275)^2 + (50)^2} = 140'$$

$$q_{ml} = \frac{\sqrt{2} \times 51}{140} \times 16.2 = 8.3 \text{ cfs/ft}$$

$$V_{ml} = \sqrt{2g(420 + 25)} = 169 \text{ ft/s}$$

$$D_{ml} = 8.3/169 = .05'$$

$$W = 169 \Big/ \sqrt{.005/1.94 \times .05} = 744$$

$$\bar{L}/D_{ml} = 1.15(744) + 30 = 886$$

$$\bar{L} = 886 \times .05 = 44.'$$ (Jet will break-up - No Plunge)

Lower level Valves:

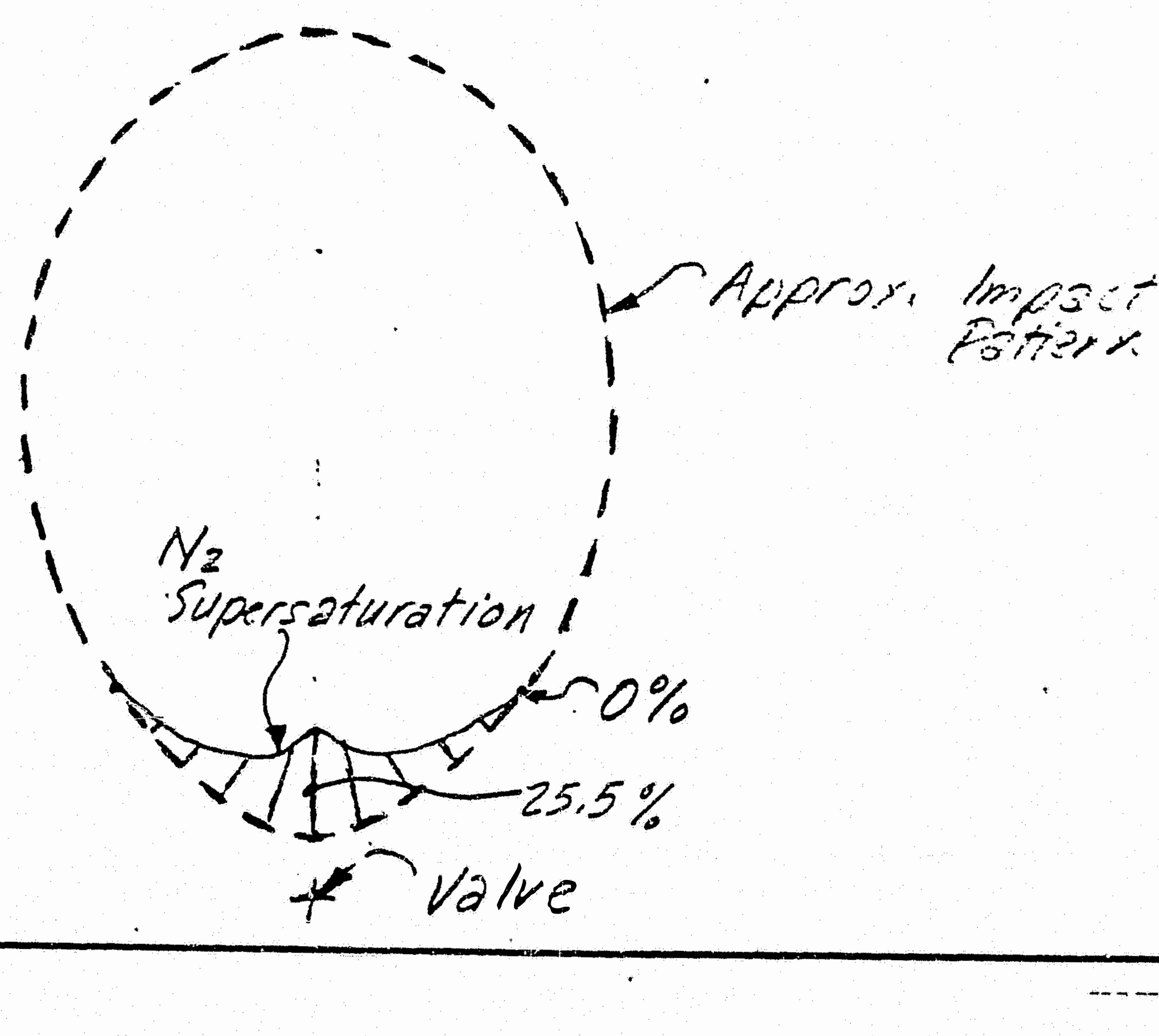
Upper half of jet will break-up and will not plunge. N_2 supersaturation = 0.

Assume lower half varies from 25.5% at lower nappe to 0% at spring-line.

Final mixed supersaturation =

$$S_f = \frac{\frac{25.5 + 0}{2} + 0}{2} = 6.1\%$$

(Each lower level valve)



Check Upper Level Valves:

HW 1455

℄ Valves 1050

Gross H = 405

Less 20% for conduit losses

$H_{net} = .8 \times 405 = 324'$

Design Q = 5800 cfs (102" valves)
$A = 56.7\ ft^2$

$5800 = C(56.7)\sqrt{2g(324)}$

$C = 0.71$ (Valve op'g ~ 63%)

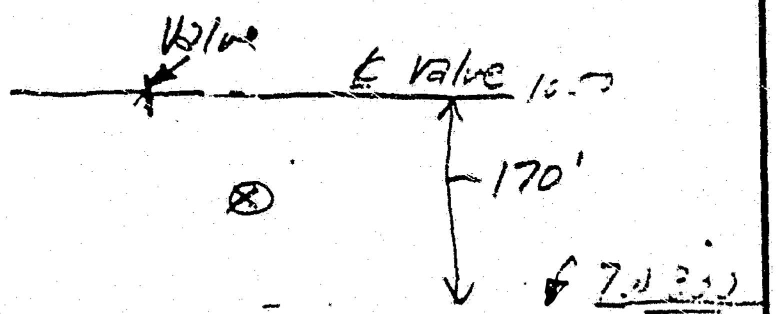
Check Lower Nappe for break-up:

At mid-length: $q = \frac{5800}{\pi(170)} = 10.9\ cfs/ft$

$V = \sqrt{2g(324 + 85)} = 162$

$D_{mi} = 10.9/162 = .067'$

$W_{mi} = 162 \Big/ \sqrt{\frac{.005}{1.94 \times .067}} = 826$



$\bar{L}/D = 1.15(826) + 30 = 980$

$\bar{L} = 980 \times .067 = 66'$

Lower Nappe Will Break-up

With Upper Valves Only - N_2 supersat. = 0

With All Valves Operating:

$$N_2 = \frac{3 \times 5100 \times 6.1 + 4 \times 5800 \times 0}{38,500}$$

$$N_2 = \underline{2.4}\%$$

With Powerhouse Operating @ 7000 cfs

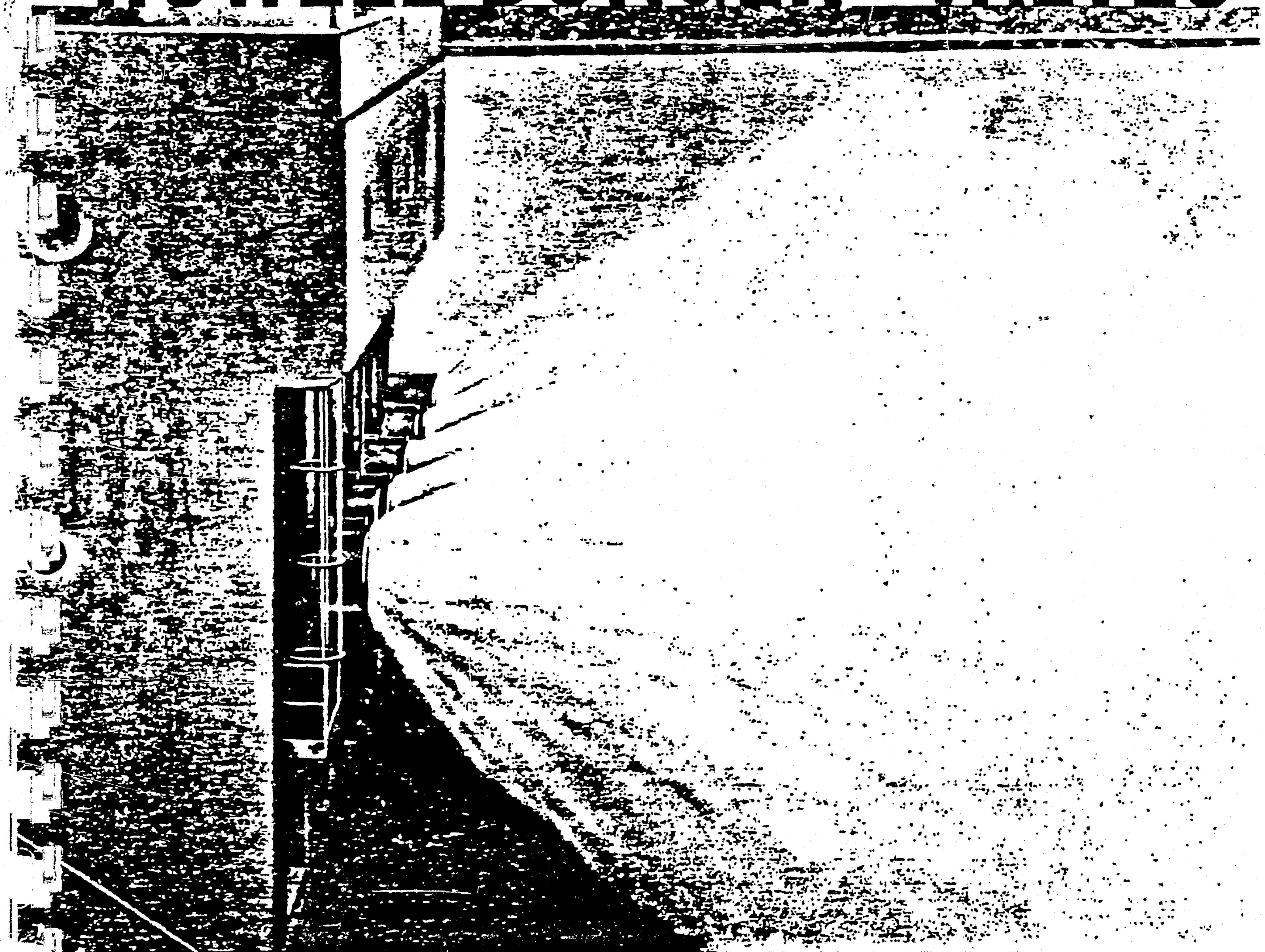
$$N_2 = \frac{3 \times 5100 \times 6.1}{38,500 + 7000} = \underline{2.1}\%$$

1 Lower Valve + Powerhouse

$$N_2 = \frac{5100 \times 6.1}{5100 + 7000} = \underline{2.6}\%$$

REFERENCE 1.

"HOWELL-BUNGER" VALVES



FOR POWER • FLOOD CONTROL • IRRIGATION • DRAINAGE
TURBINE BYPASS • AERATION OF WATER

ALLIS-CHALMERS

"HOWELL-BUNGER" VALVES

provide easy, efficient regulation and control of water under free discharge

Howell-Bunger valves have a wide range of application where easy, efficient regulation and control of water flow under free discharge is demanded. These valves are used to pass a controlled amount of water downstream for power requirements, flood control or irrigation, or to drain a reservoir or pond. They may be used as turbine bypass valves . . . and also for the aeration of water.

A remarkable record of performance in these various applications, together with many other advantages, has made the *Howell-Bunger* valve the leader among balanced free-discharge valves. In addition, its initial cost is much lower than that of any other type of balanced free-discharge valve.

Advanced design of the *Howell-Bunger* valve provides efficient free-discharge operation for both high and low heads. It operates without excessive vibration or pitting, and with negligible maintenance.

Because the valve has a very high coefficient of discharge, pipelines or conduits can be kept to a minimum size for economical construction.

Only one moving part — the cylinder gate which operates over the valve ports — is in contact with the stream flow. Moreover, this cylinder gate is subject only to well-balanced hydraulic forces and requires little effort to operate it at any position of gate stroke from "fully open" to "fully closed."

The *Howell-Bunger* valve controls and helps dissipate an enormous amount of energy (without damage to the valve, operating equipment or surrounding structure) by breaking up the discharge into a large, hollow, expanding jet.

The *Howell-Bunger* valve is installed at the free end of a pipeline or conduit and discharges either into atmosphere or into water. When the valve discharges into atmosphere, the issuing jet breaks up the water into a fine spray (see Fig. 2) which helps prevent the formation of "pot holes" in the bed of a stream.

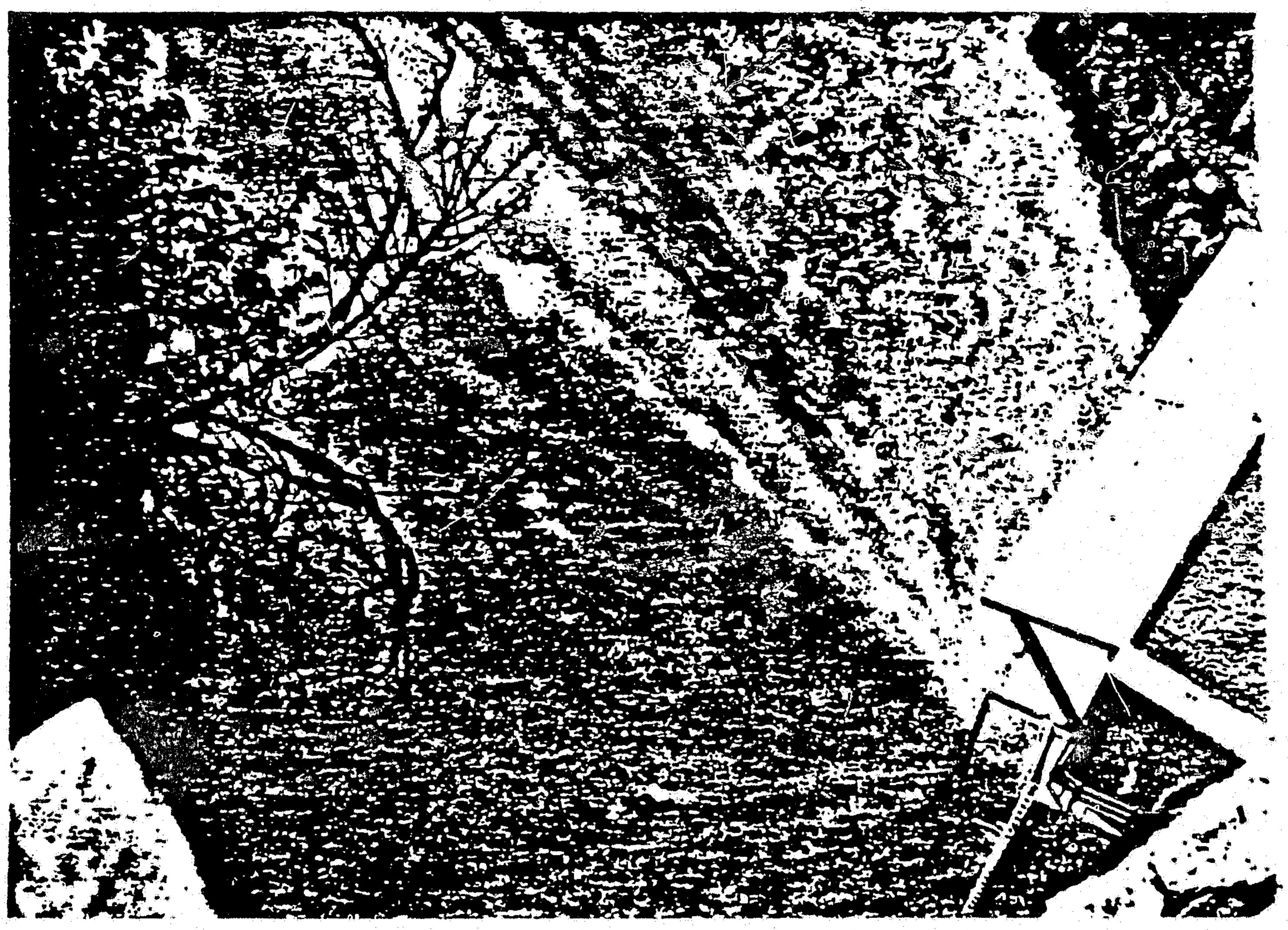


FIG. 2 — One of three 96-inch *Howell-Bunger* valves discharging at 1/6 gate opening under 170-feet head at the U.S. Engineers Mud Mountain Dam, White River, Wash. (See Fig. 11 for a detailed installation drawing.)

In cases where it is desirable to confine the normal expansion of the discharge jet, the valve is located in the discharge chamber or hood. It also may be installed for discharge directly into a tunnel. The application sketches on the opposite page and throughout this bulletin show some of the arrangements generally used.

Size of the valve is determined by the maximum available net head at the valve. Net head is the distance between head water elevation and the centerline of the valve (or if the valve is submerged — the tail water elevation) less the inlet, conduit, bend or other friction losses. The graph (Fig. 7) shows the maximum calculated discharge for valve sizes 8 inches to 108 inches, based on net heads up to 500 feet.

This graph is based on an average coefficient of discharge of .85, although field tests show a higher value for the larger-size valves. Maximum values for other heads can be determined from the formula:

$$Q = C \times \sqrt{2gH} \times A$$

where Q = cubic feet per second (cfs).

C = coefficient of discharge with valve full open = .85.

g = acceleration due to gravity = 32.2.

H = net head in feet.

A = area of valve in square feet (based on nominal inside diameter).

Using a coefficient of discharge of .85, this formula can also be expressed as

$$Q = 5.354\ D^2 \sqrt{H}$$

where D is the diameter of the valve in feet.

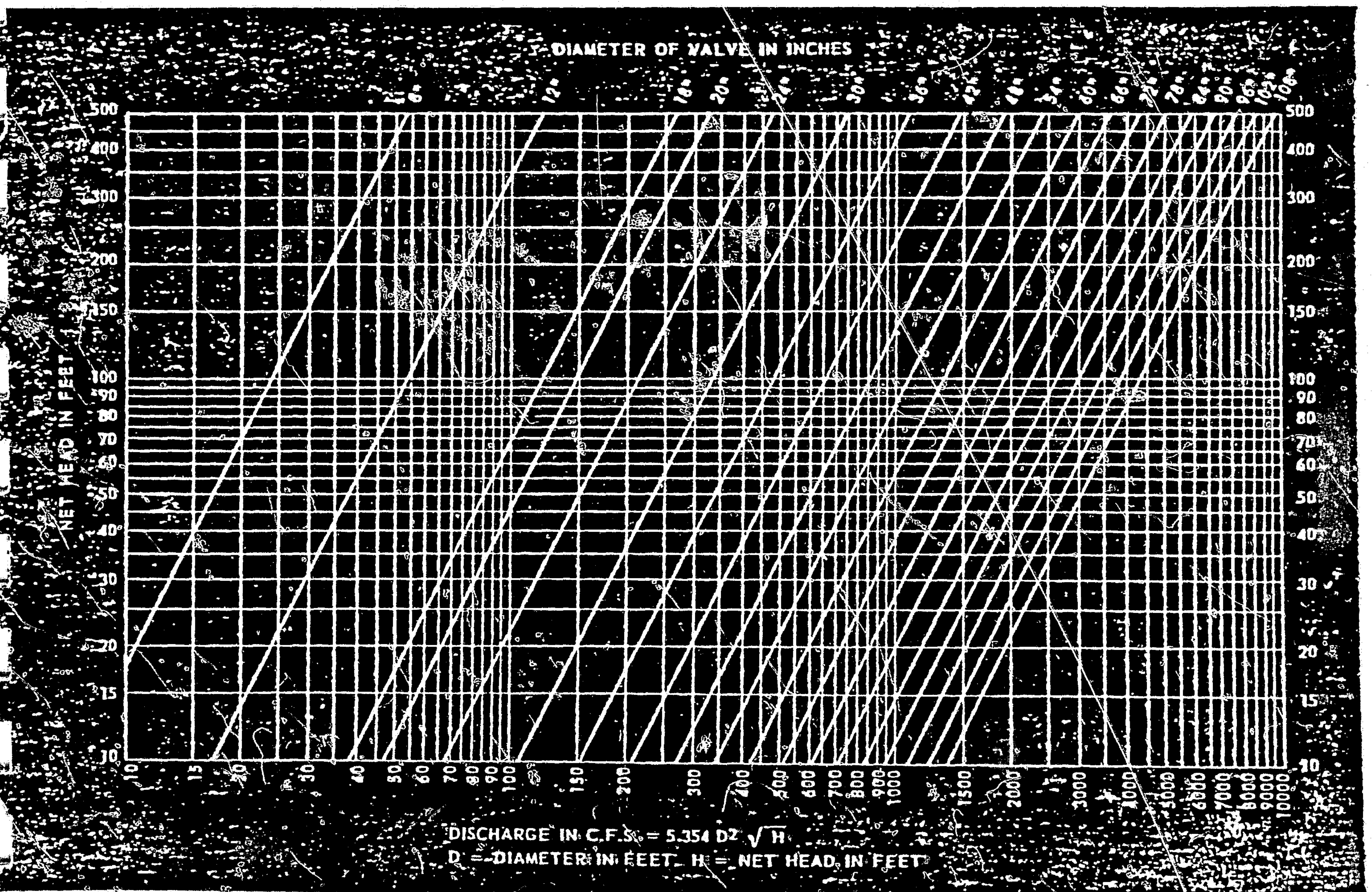


FIG. 7 — VALVE SELECTION CHART. To determine discharge of any size valve, follow horizontal line for given head to point where it crosses diagonal line representing valve size. From this point, follow vertical line to bottom of chart, and read discharge in cfs.

Average values for discharge coefficient have been determined from field and laboratory tests. These values make it possible to predict quite accurately what the discharge will be for *any* size valve under *varying* heads for *any* position of gate stroke from "fully open" to "fully closed."

The gate position indicator (shown in Fig. 1) is graduated into ten increments. With the values given below, a curve sheet can be plotted in tenths of the gate stroke so that an operator can tell at a glance where to position the gate to discharge the required amount of water at the available head. Figure 8 shows such a curve for a 48-inch valve.

$$\text{Discharge in cfs} = K \times D^2 \sqrt{H}$$

where D = the diameter of the valve in feet.
H = net head in feet.

Standard *Howell-Bunger* valves are available in sizes up to 108 inches. Large-size valves have been installed for heads up to 420 feet, and smaller sizes for heads up to 900 feet. Dimensions of valves 18 inches and over are shown in Fig. 10 on the following page, and 8 and 12-inch valves are available in the design shown in Fig. 23. Additional sizes for special applications can be provided. Valves almost 14 feet in diameter have been considered. Valves of all sizes may be motor-operated and those above 42 inches are rarely operated by hand. Sizes below 18 inches usually have manually operated mechanisms as shown in Fig. 23 on page 13.

All free-discharge valve installations should include provisions for unwatering the supply pipe. Stop logs, gates, butterfly or Dow valves may be used for this purpose.

Percentage of gate stroke	10	20	30	40	50	60	70	80	90	100
K (average value)	0.882	1.700	2.394	3.150	3.716	4.283	4.724	5.039	5.260	5.354

FIG. 8