U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO
THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PHYSICAL CHARACTERISTICS OF AIR CIRCULATION THROUGH YUCCA MOUNTAIN

PRESENTER: EDWIN P. WEEKS

PRESENTER'S TITLE AND ORGANIZATION: HYDROLOGIST
U.S. GEOLOGICAL SURVEY
DENVER, COLORADO

PRESENTER'S TELEPHONE NUMBER: (303) 236-4981

REGISTRY HOTEL, DENVER COLORADO
JUNE 25-27, 1991

GAS FLOW THROUGH FRACTURES

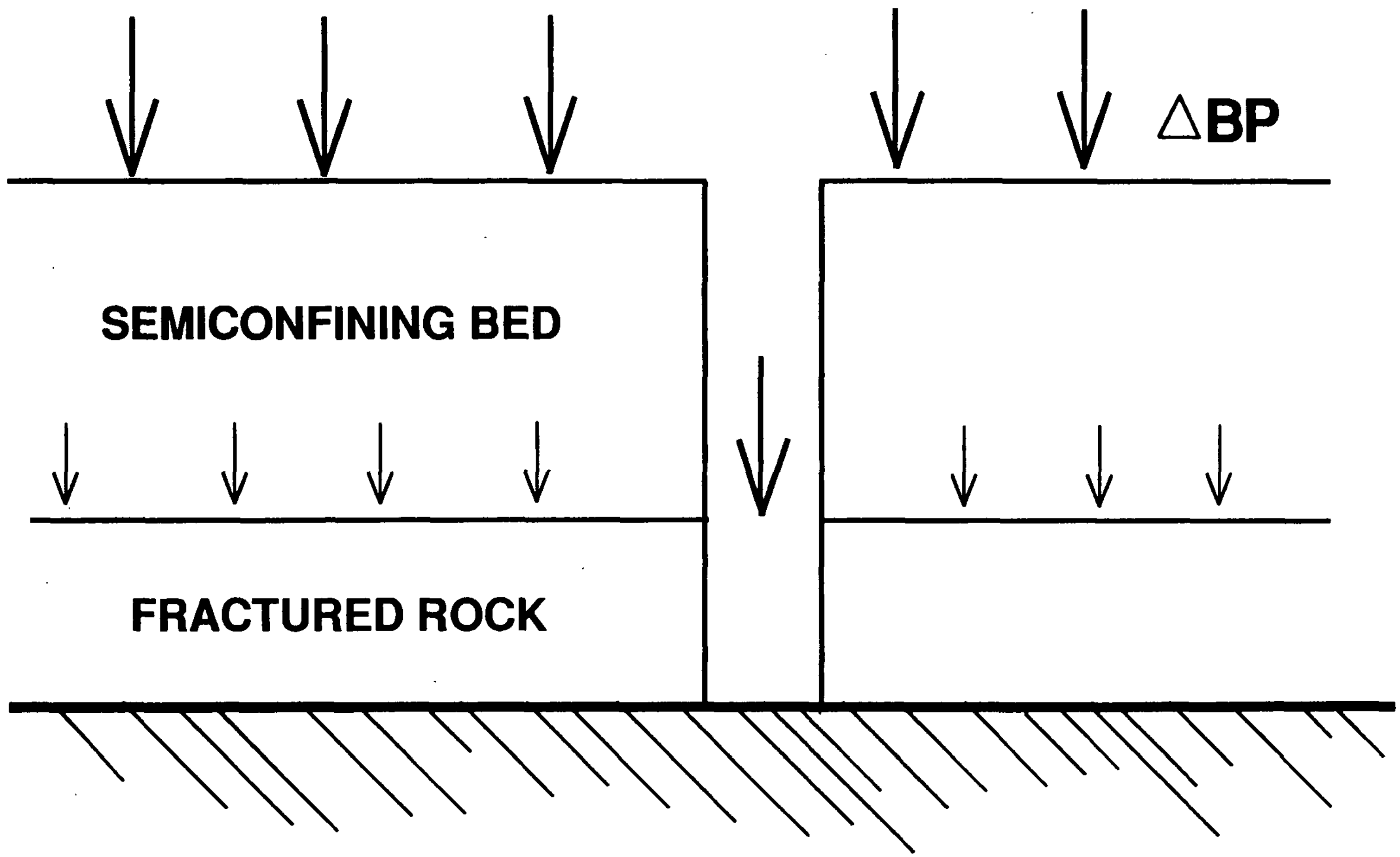
- IN THE VICINITY OF YUCCA MOUNTAIN, SUBSTANTIAL AIRFLOW HAS BEEN OBSERVED IN MOST WELLS DRILLED THAT HAVE A SECTION OF OPEN HOLE ABOVE THE WATER TABLE

- TYPICALLY, THE OBSERVED FLOWRATES ARE SO GREAT THEY CAN ONLY BE EXPLAINED AS FRACTURE-FLOW PHENOMENA

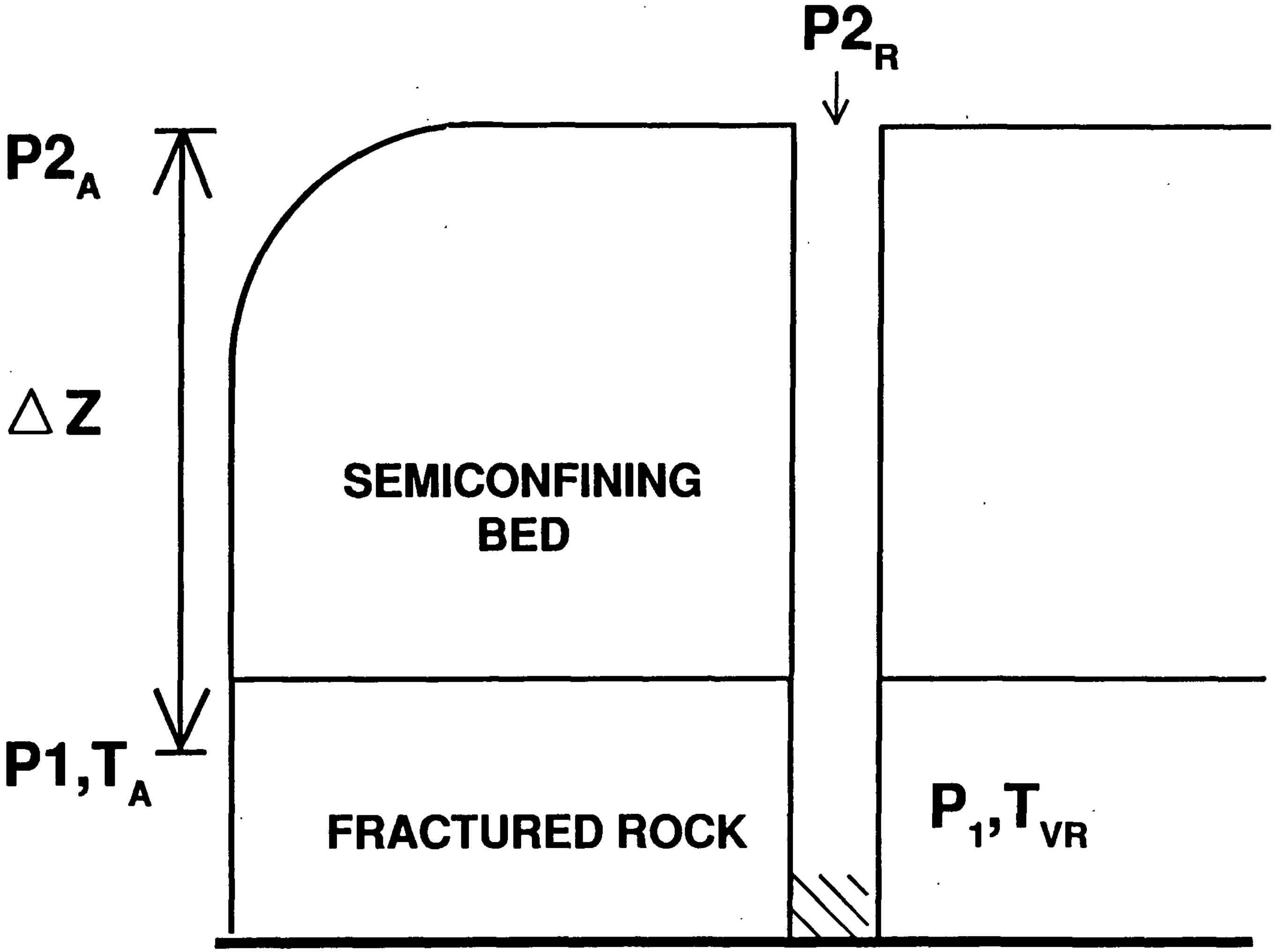
- TWO DIFFERENT DRIVING MECHANISMS PRODUCE THESE FLOWS:

  - CHANGES IN BAROMETRIC PRESSURE
  - TOPOGRAPHICALLY-AFFECTED DENSITY-DRIVEN FLOW

BAROMETRIC EFFECT



TOPOGRAPHIC EFFECT



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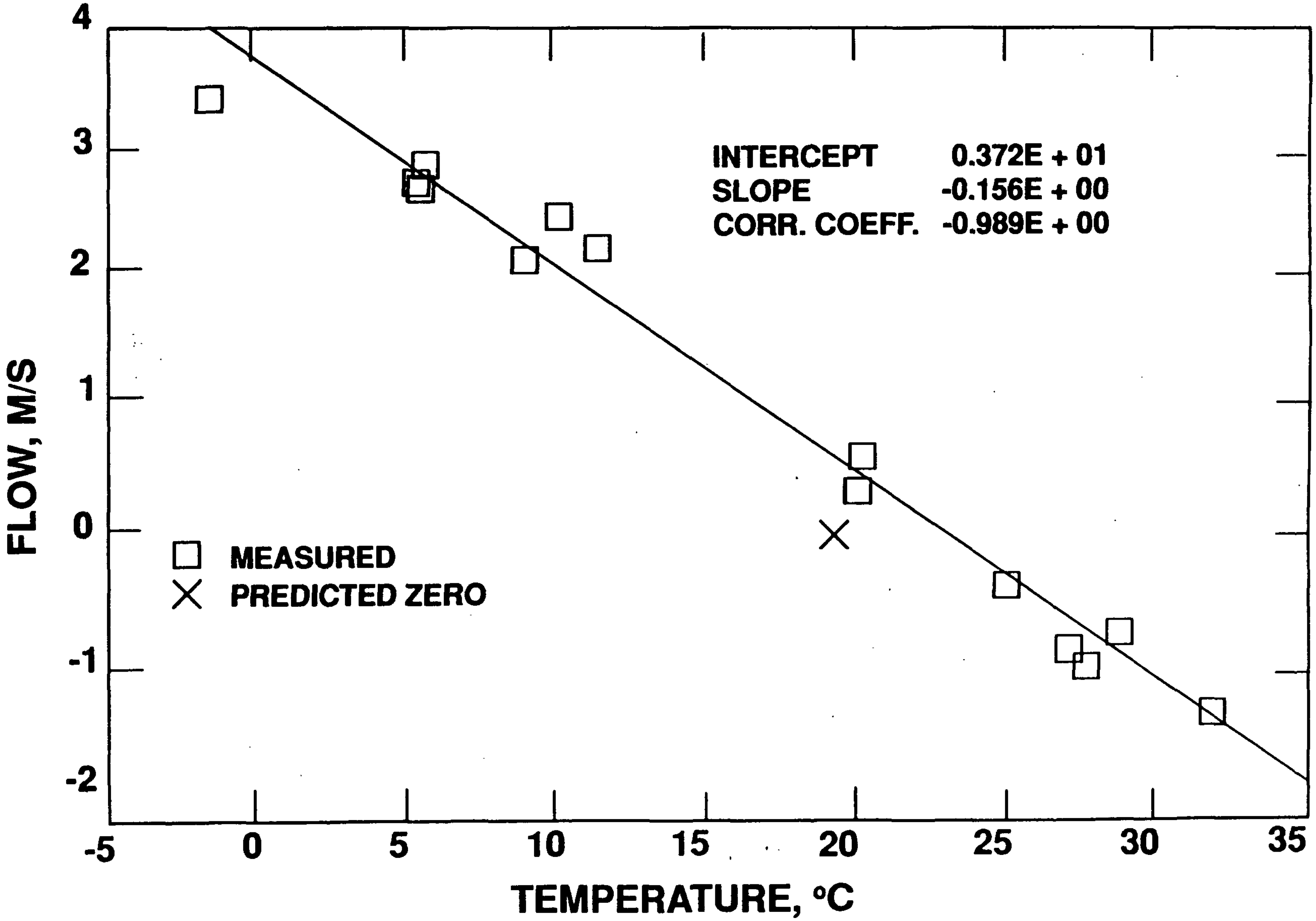
PHOTOGRAPH:
OBLIQUE AERIAL VIEW
OF YUCCA MOUNTAIN

PHOTOGRAPH:
BLOWING WELL, UZ6S

TYPICAL DAILY WINTER FLUXES FROM WELL UZ6S

ROCK GAS	10,000 CUBIC METERS
WATER VAPOR (GROSS)	145 LITERS
WATER VAPORT (NET)	100 LITERS
CARBON, GROSS (AS CO_2)	3.3 KILOGRAMS
CARBON, NET (AS CO_2)	2.3 KILOGRAMS

FLOW vs. TEMP., 10-DAY AVERAGES, UZ6S



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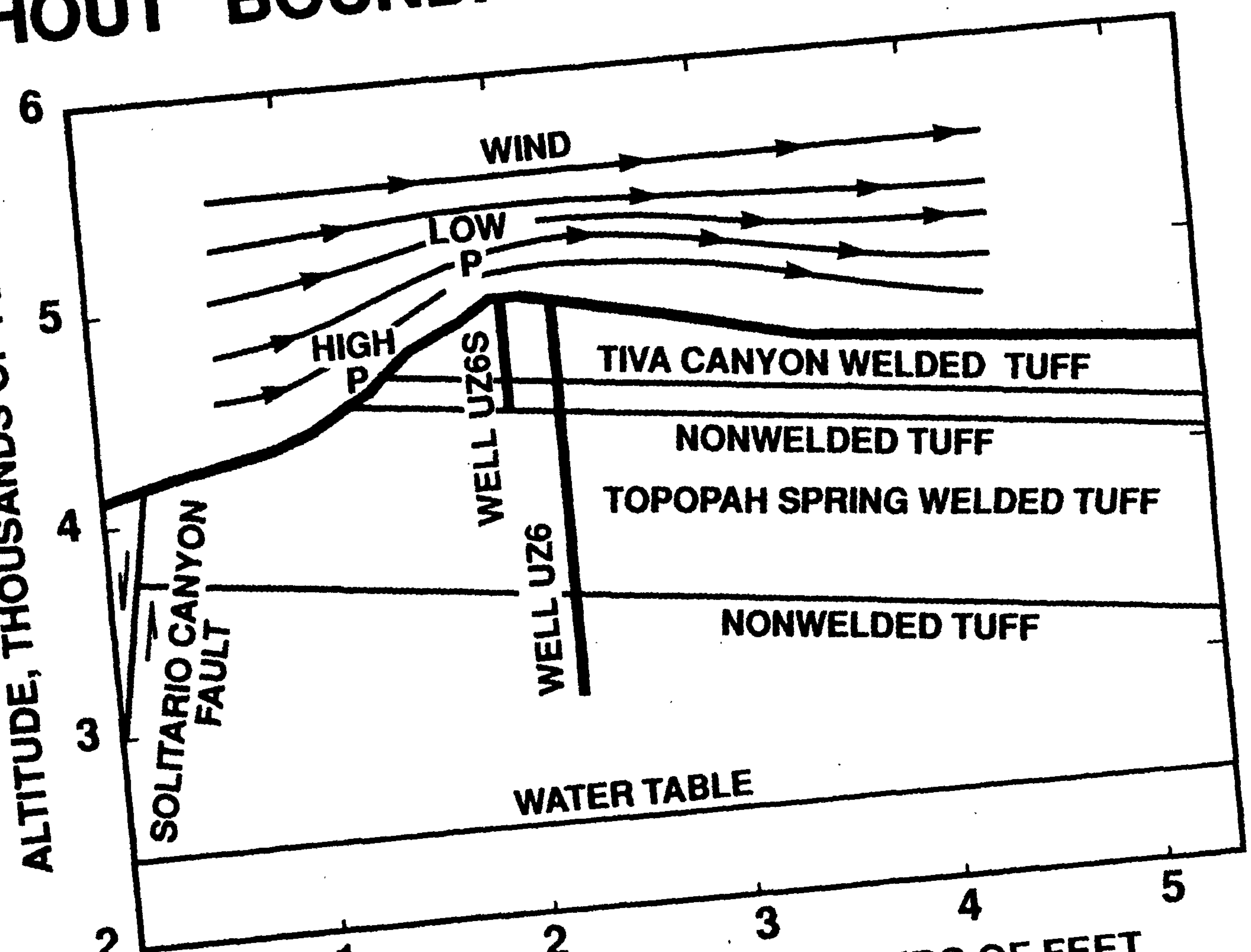
YUCCA MOUNTAIN CROSS SECTION AT WELL UZ6S SHOWING WIND EFFECT WITHOUT "BOUNDARY LAYER SEPARATION"



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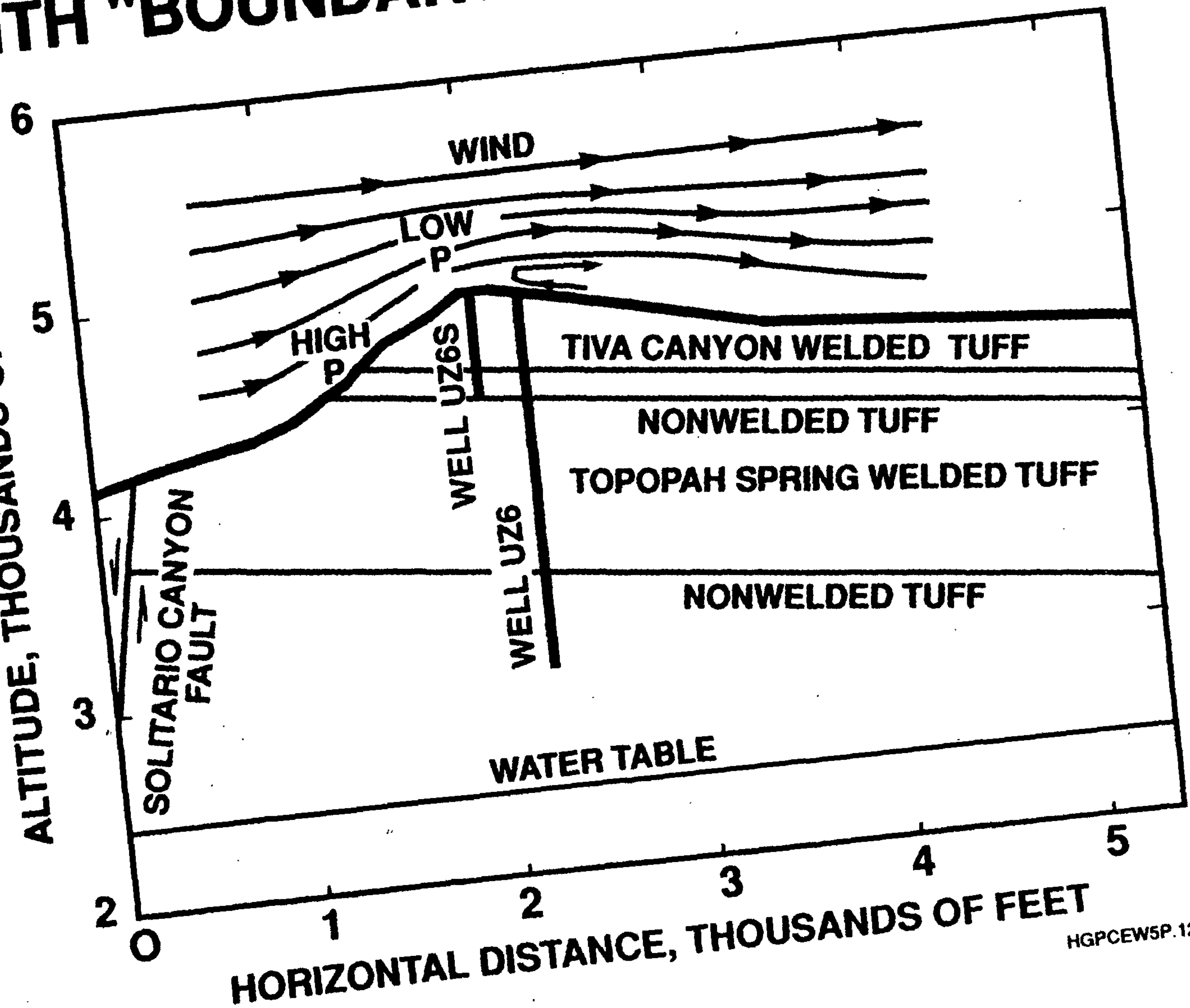
YUCCA MOUNTAIN CROSS SECTION AT WELL UZ6S SHOWING WIND EFFECT WITH "BOUNDARY LAYER SEPARATION"



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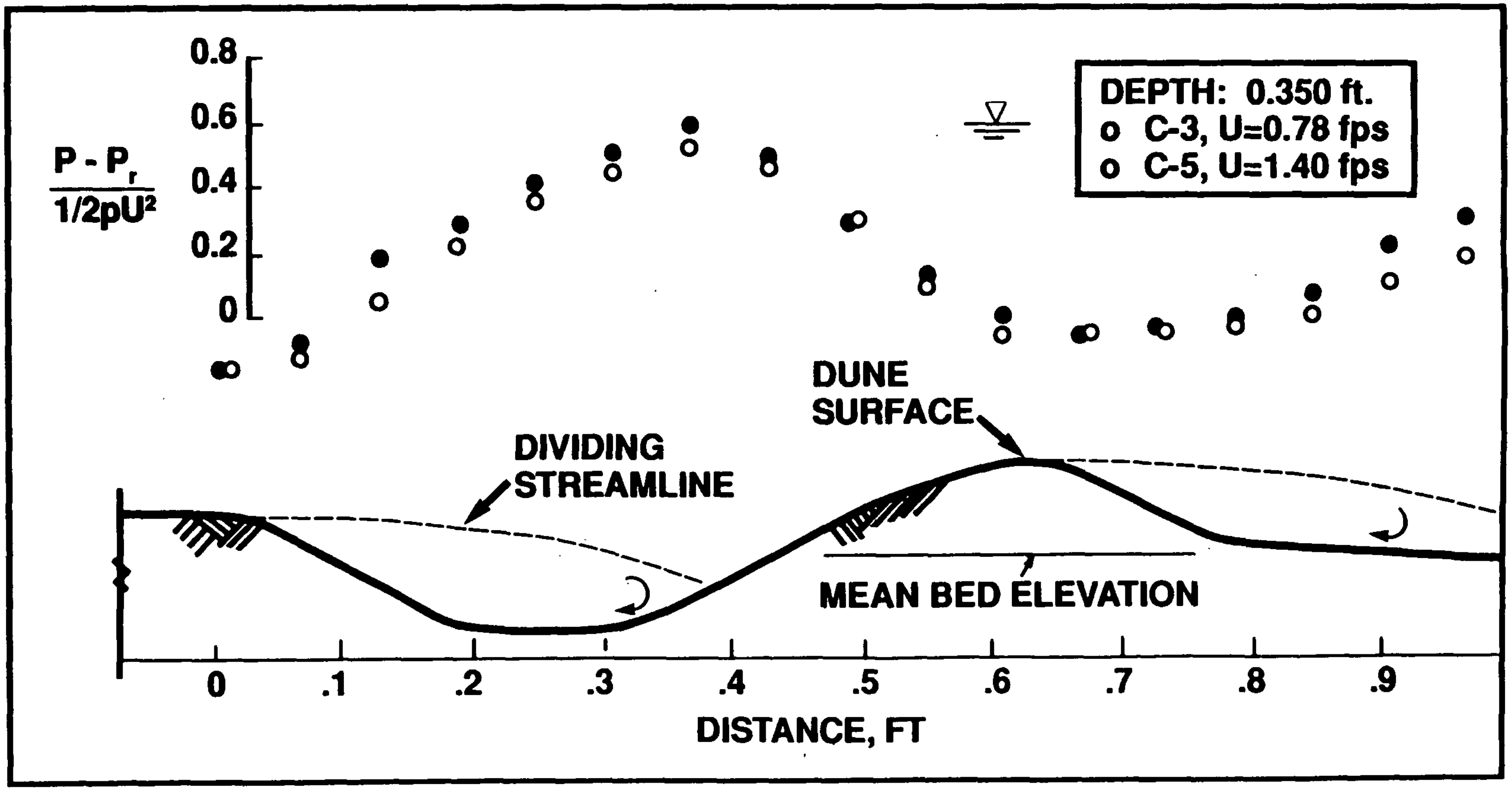
EXPERIMENTAL FLUME DATA DEMONSTRATING THE EFFECTS OF FLUID FLOW ON THE PRESSURE POTENTIAL AT THE SURFACE OF A TOPOGRAPHIC FEATURE (AFTER VANONI AND HWANG, 1967)



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REFERENCE

VANONI, V.A., AND HWANG, LI-SAN, 1967, RELATION BETWEEN BED FORMS AND FRICTION IN STREAMS: AM. SOC. CIVIL ENGINEERS, JOURNAL OF THE HYDRAULICS DIVISION, v. 93, no. HY3, p. 121-144

REGRESSION EQUATION DESCRIBING THE RELATIONSHIP BETWEEN AIR FLOW IN WELL UZ6S AND VARIOUS WEATHER PARAMETERS

$$V_{WLC} = 0.523 - 0.313(P_0 - PBAR) - 9.81(P_0 - P_2) - 0.204T_C + g(\theta)U^{1.5},$$

WHERE:

V_{WLC} = WELL-LOSS CORRECTED FLOW VELOCITY, M/S;

P_0 = BAROMETRIC PRESSURE AT END OF CURRENT HOUR, kPa;

PBAR = MEAN BAROMETRIC PRESSURE, kPa;

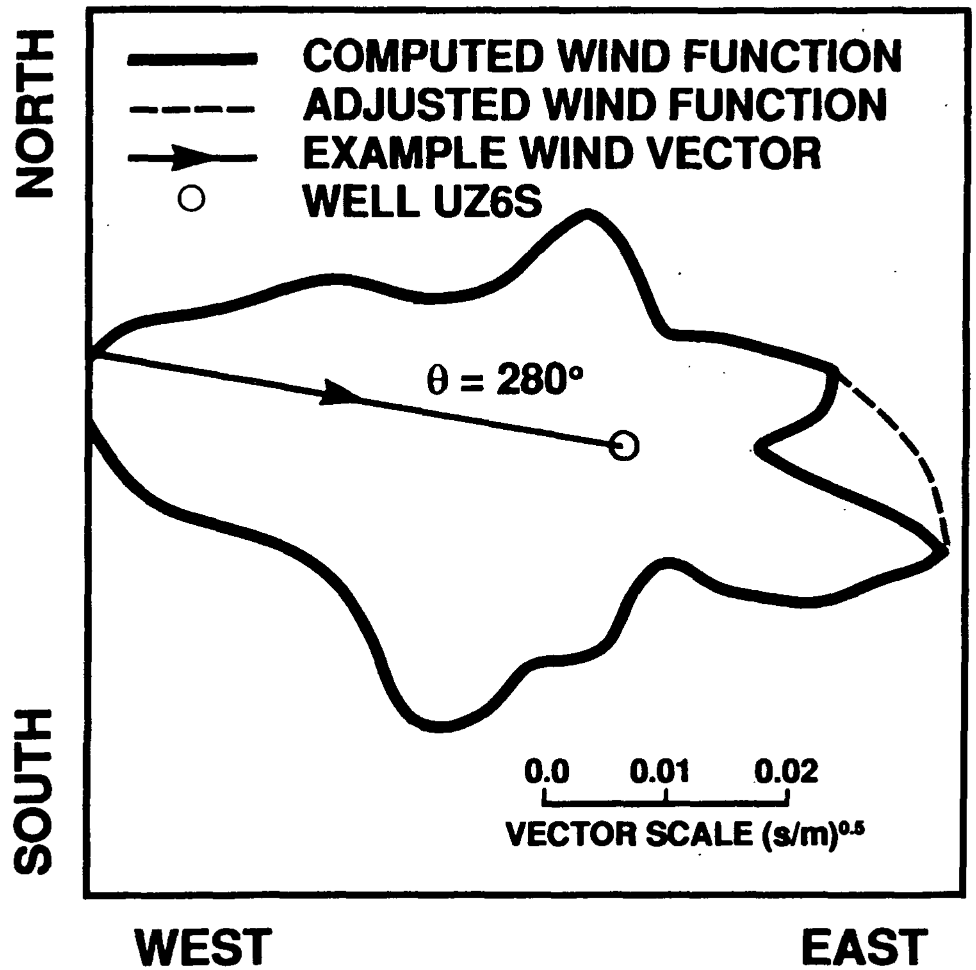
P_2 = BAROMETRIC PRESSURE 2 HOURS PREVIOUSLY, kPa;

T_C = DENSITY-ADJUSTED TEMPERATURE DIFFERENCE FROM 20 °C;

$g(\theta)$ = DIRECTION DEPENDENT WIND INFLUENCE FUNCTION, $(S/M)^{0.5}$; AND

U = WIND SPEED AT A HEIGHT OF 10 m, M/S

GRAPH OF WIND INFLUENCE FUNCTION VERSUS WIND DIRECTION



ADJUSTMENT IS TO REMOVE PRESUMED EFFECTS OF CUT BANK OF UZ6 PAD

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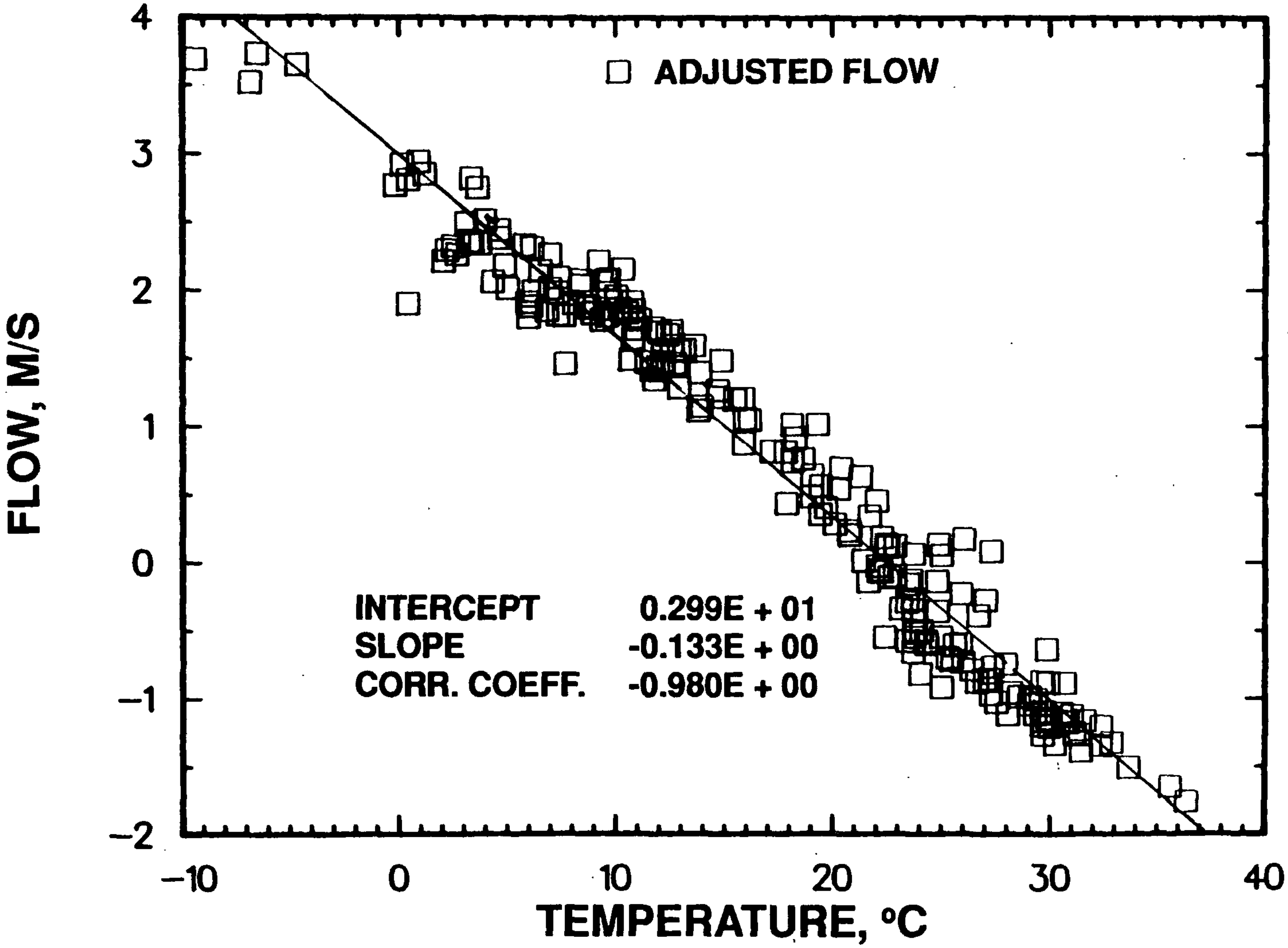
PLOT OF FLOW IN WELL UZ6S ADJUSTED FOR WIND AND BAROMETRIC EFFECTS VERSUS AIR TEMPERATURE



THE S-SHAPED CURVE DESCRIBED BY THE DATA REFLECT THE EFFECTS OF WELL-BORE FRICTION

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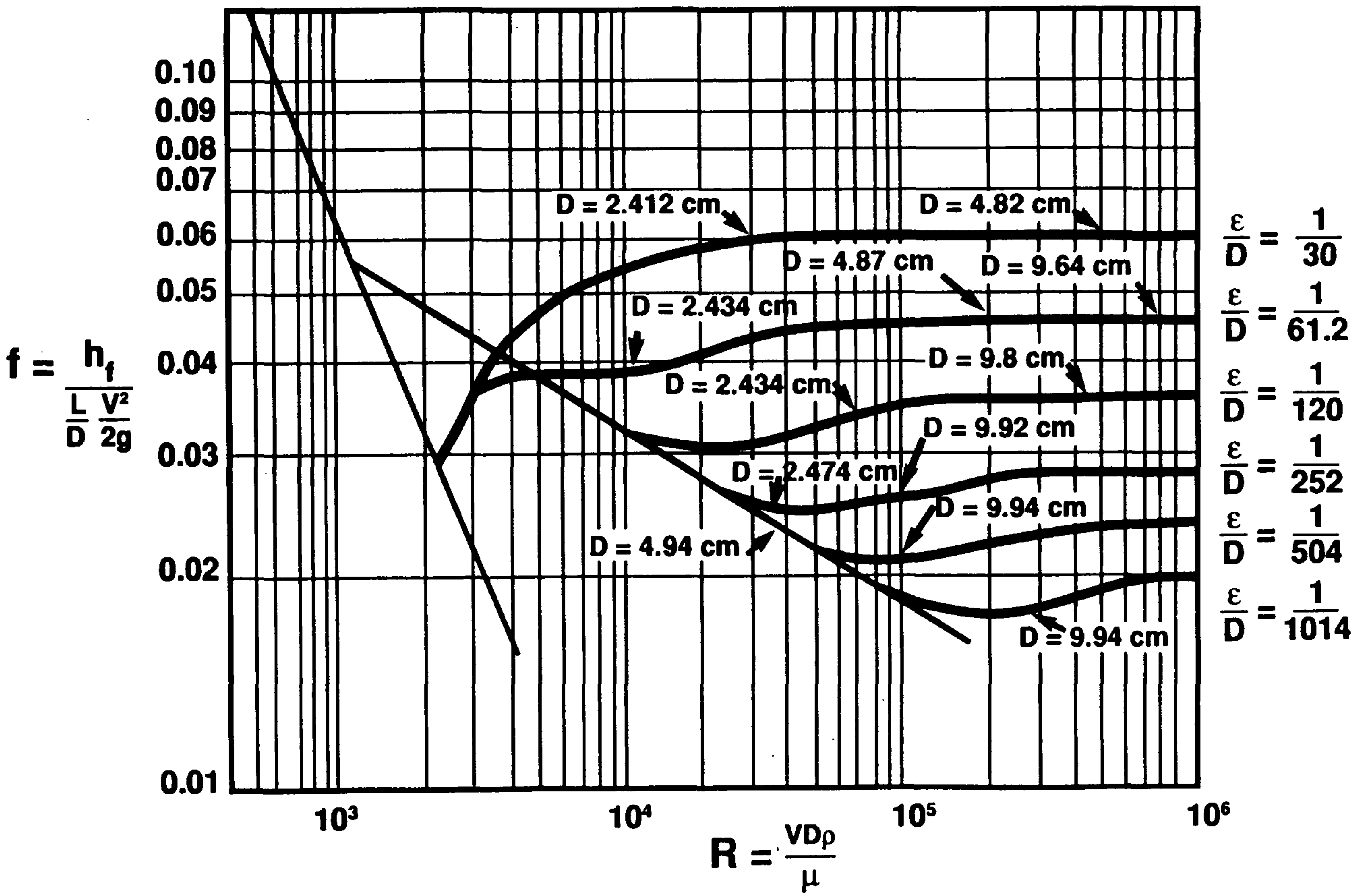
EQUATION FOR PRESSURE LOSSES DUE TO FRICTION DURING FLOW IN PIPES OR WELLBORES

$$P_f = \frac{fL\rho V^2}{2D}$$

WHERE:

f = REYNOLDS-NUMBER DEPENDENT FRICTION FACTOR;
L = LENGTH OF PIPE OR WELLBORE, m;
D = PIPE OR WELLBORE DIAMETER, m;
ρ = FLUID DENSITY, kg/m^3 AND,
V = FLOW VELOCITY, m/s

GRAPH SHOWING RELATIONSHIP BETWEEN REYNOLDS NUMBER AND FRICTION FACTOR IN TRANSITION RANGE



AFTER STREETER, 1962, FLUID MECHANIC[illegible] McGRAW-HILL

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EFFECTS OF WELLBORE FRICTION LOSSES ON FLOW IN WELL UZ6S

AT A FLOW RATE IN WELL UZ6S OF 20 °C AIR AT 1.0 m/s, THE REYNOLDS NUMBER (Re) IS 10^4. FOR Re BETWEEN $3x10^3$ AND 10^5, FLOW IS IN THE TRANSITION RANGE BETWEEN LAMINAR AND FULLY TURBULENT, AND THE FRICTION FACTOR f VARIES AS C_1 ($Re^{-1/4}$). SINCE Re VARIES AS C_2 (V) FOR ISOTHERMAL FLOW,

$$P_f = L\rho C_1 C_2 V^{1.75} /2D$$

OR, AFTER INSERTING PROPER VALUES FOR THE VARIOUS CONSTANTS,

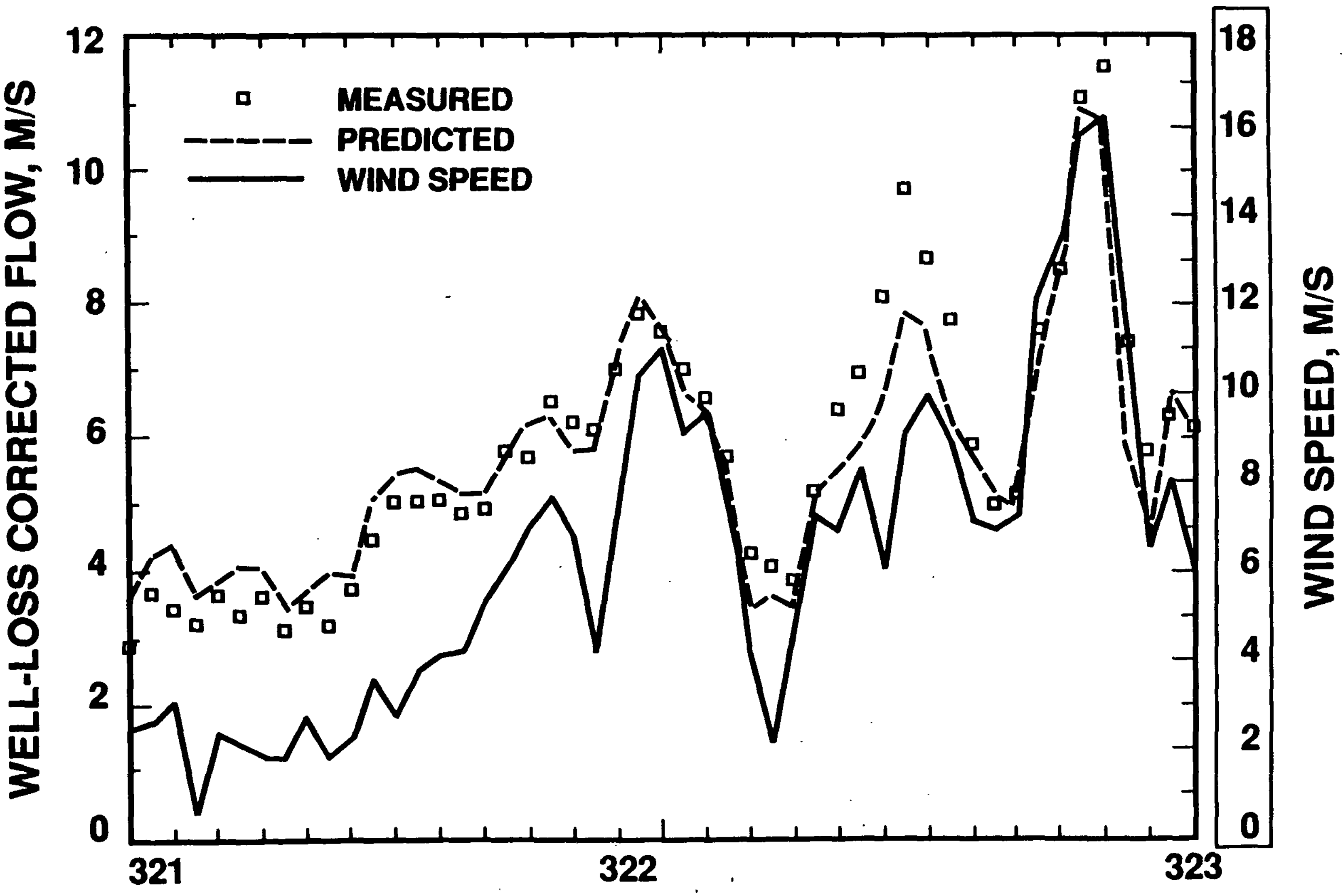
$$P_f = 0.25V^{1.75}$$

IT CAN BE SHOWN THAT FLOW VELOCITY IN THE ABSENSE OF WELL LOSSES, V_{WLC}, IS GIVEN BY THE EQUATION:

$$V_{WLC} = V + .25 (V^{1.75})$$

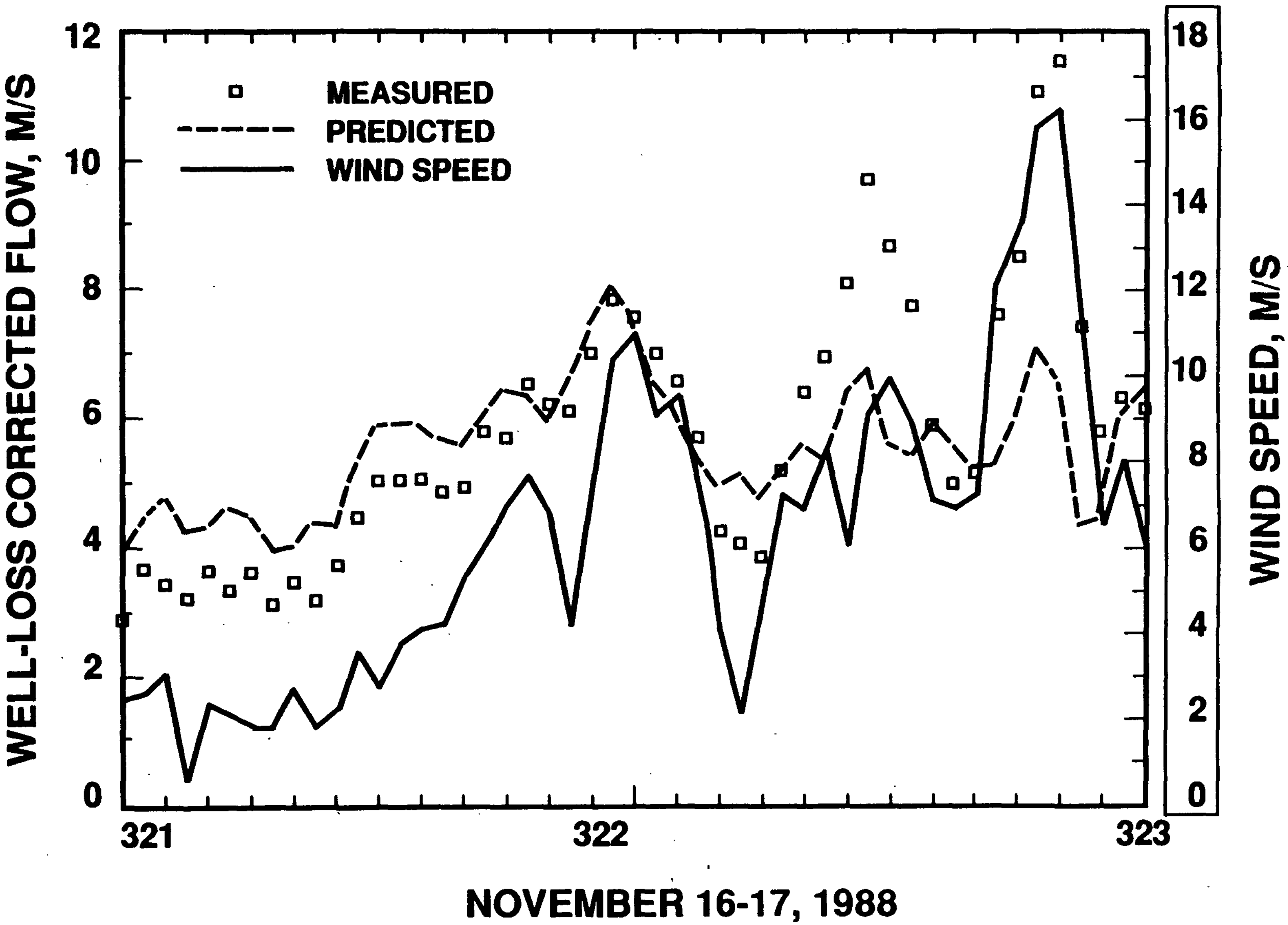
WHERE V IS MEASURED FLOW VELOCITY, m/s

FLOW PREDICTED IN WELL UZ6S WITH WIND EFFECTS



NOVEMBER 16-17, 1988

FLOW PREDICTED IN WELL UZ6S WITHOUT WIND EFFECTS



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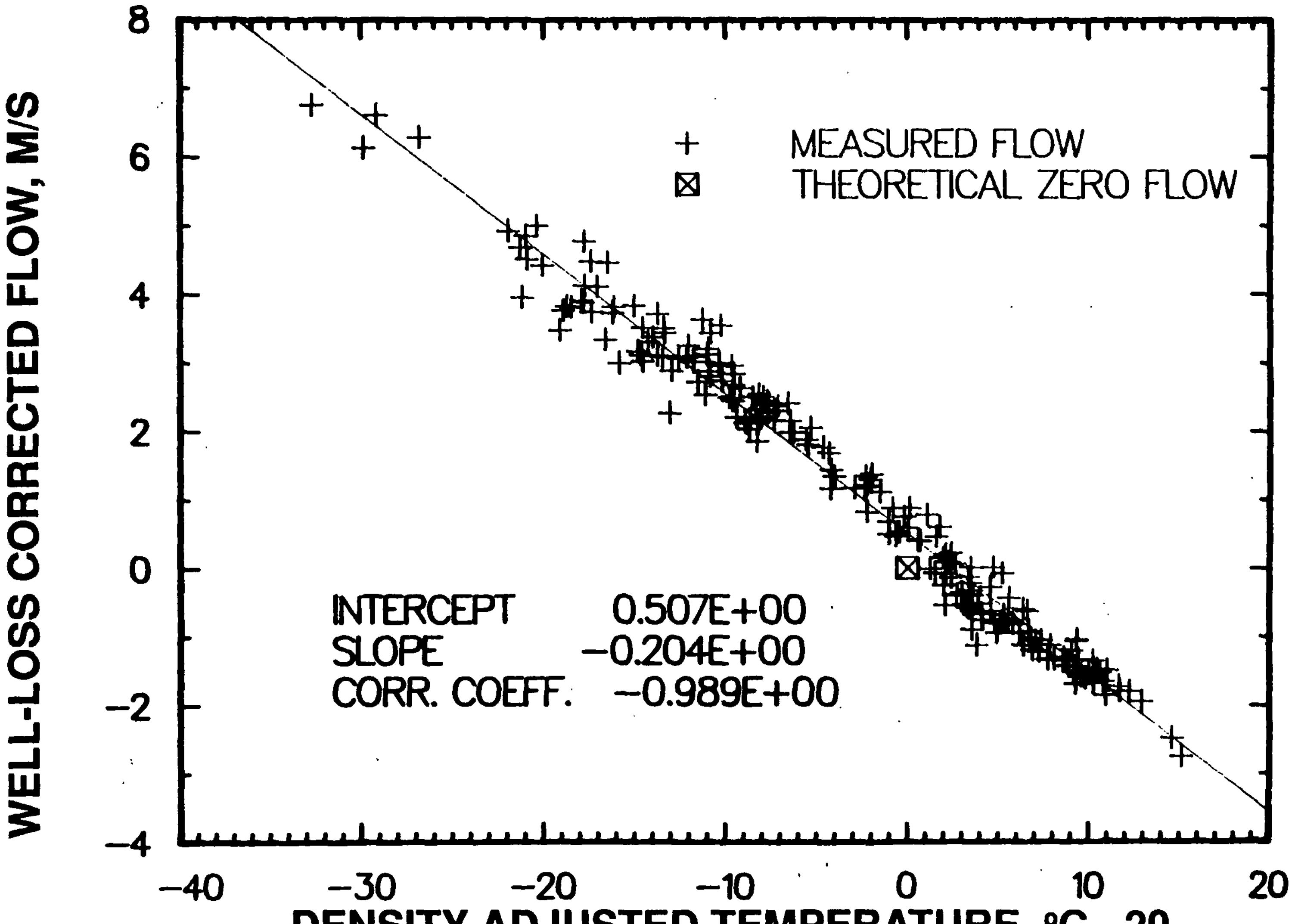
PLOT OF FLOW IN WELL UZ6S ADJUSTED FOR WIND AND BAROMETRIC EFFECTS AND FOR WELL-BORE LOSSES vs. DENSITY-ADJUSTED TEMPERATURE



EQUATION DESCRIBING THE DIFFERENCE IN PRESSURE POTENTIAL BETWEEN A COLUMN OF GAS AND A COLUMN OF AIR OF THE SAME HEIGHT BUT DIFFERENT TEMPERATURE

$$\Delta P = P_1\left[\exp\left(\frac{-g\Delta z}{R_A T_{RV}}\right) - \exp\left(\frac{-g\Delta z}{R_A T_{AV}}\right)\right],$$

WHERE:

ΔP = PRESSURE DIFFERENCE AT WELLHEAD, Pa

P_1 = ATMOSPHERIC PRESSURE AT WELLHEAD ALTITUDE, Pa

g = ACCELERATION DUE TO GRAVITY, m/s^2

Δz = DIFFERENCE IN ALTITUDE BETWEEN HILLSLOPE FRACTURED ROCK OUTCROP AND WELL HEAD, m

R_A = AIR-SPECIFIC GAS CONSTANT, J/kgK

T_{RV} = VIRTUAL TEMPERATURE OF ROCK GAS, K; AND

T_{AV} = VIRTUAL TEMPERATURE OF ATMOSPHERIC AIR, K

VIRTUAL TEMPERATURE IS DEFINED AS THE TEMPERATURE AT WHICH DRY AIR WOULD HAVE THE SAME DENSITY AS AIR WITH ITS PREVAILING MOISTURE CONTENT AND TEMPERATURE

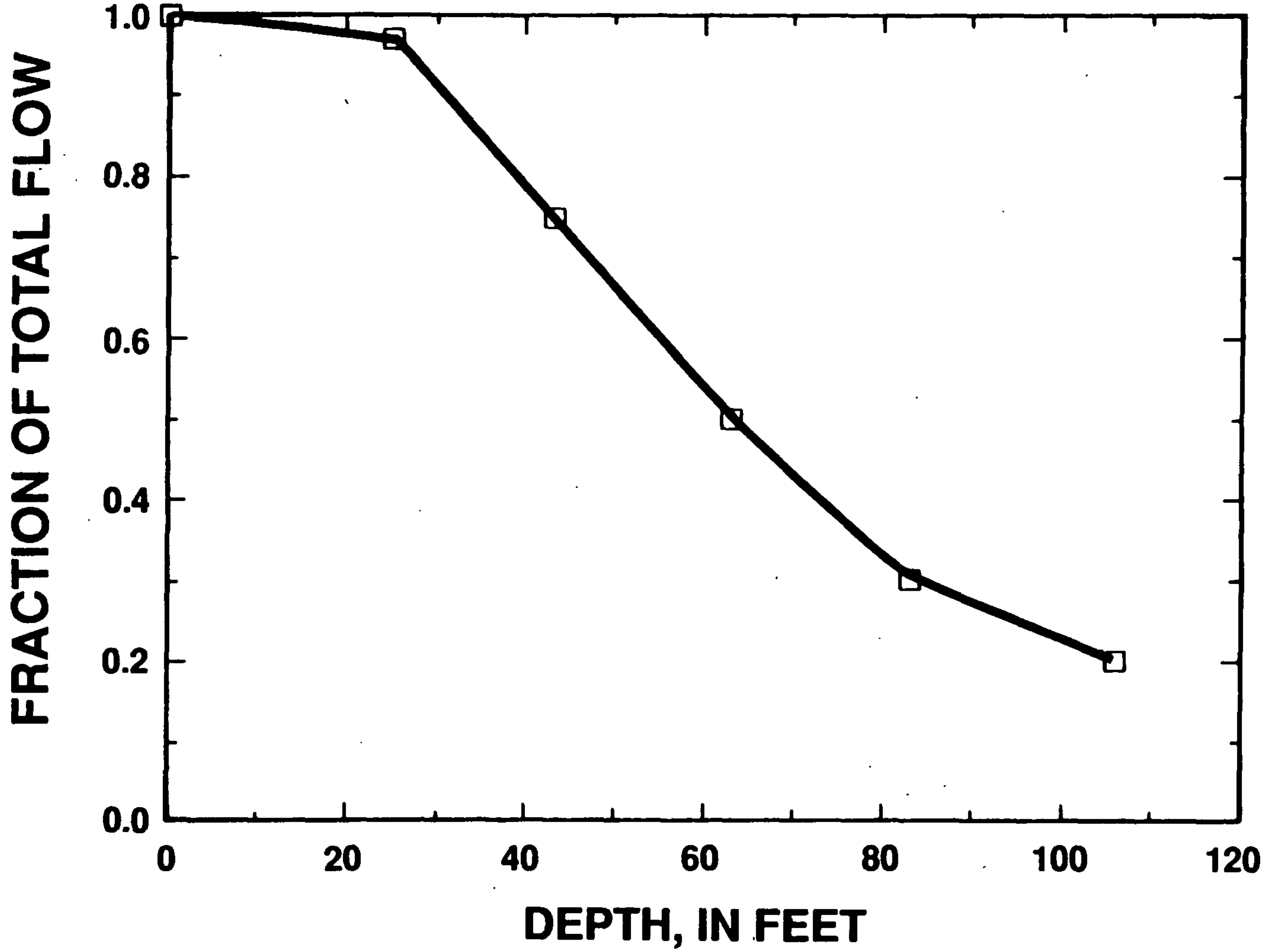
ESTIMATE OF FLOW VELOCITY RESPONSE IN WELL UZ6S DUE TO A TEMPERATURE-INDUCED PRESSURE DIFFERENCE

- **FLOW LOG INDICATES THAT THE MIDPOINT FOR FLOW ENTERING WELL UZ6S IS AT A DEPTH OF 20 METERS**

- **ENTRY OF THIS DEPTH INTO THE ΔP-TEMPERATURE EQUATION INDICATES A PRESSURE DIFFERENCE OF 0.7 PASCAL PER DEGREE CELCIUS**

- **SLOPE OF THE FLOW VELOCITY-TEMPERATURE REGRESSION IS 0.2 METERS/SECOND/ °C. HENCE, V (METERS/SECOND) = 0.3 ΔP (PASCALS)**

FLOW LOG FOR UZ6S, MARCH 1988



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EQUATION FOR PRESSURE DISTRIBUTION AT LAND SURFACE DUE TO WIND BLOWING ACROSS A SEQUENCE OF SINUSOIDALLY-SHAPED RIDGES

- **ASSUME THAT THE CROSS-SECTIONAL ALTITUDE OF THE RIDGES IS GIVEN BY THE EQUATION:**
  $Z = H(\sin(2\pi x/\lambda))$,
  WHERE z = ALTITUDE, m; H = AMPLITUDE, m;
  x = HORIZONTAL DISTANCE, m; AND λ = WAVE LENGTH, m

- **THEN THE PRESSURE POTENTAIL GENERATED AT THE SURFACE BY WIND BLOWING AT AN UNOBSTRUCTED VELOCITY U IN m/s IS GIVEN, IF ρ IS IN kg/CUBIC METER, BY THE EQUATION:**

  $$P = (\pi H/\lambda)\cos(2\pi x/\lambda)\rho U^2$$

- **REFERENCE: COLBECK, S.C., 1989, AIR MOVEMENT IN SNOW DUE TO WINDPUMPING: JOURNAL OF GLACIOLOGY, v. 35, p. 209-213**

COMPARISON OF TEMPERATURE-DEPENDENT AND WIND-DEPENDENT FLOWS IN WELL UZ6S, BASED ON THE THEORETICAL WIND-GENERATED PRESSURE POTENTIAL

- ASSUME THAT THE AIR-ENTRY POINT FOR WIND-GENERATED FLOW IS THE SAME AS THAT FOR TEMPERATURE-GENERATED FLOW - NAMELY 20m BELOW THE CREST. HENCE, $\sin(2\pi x/\lambda) = 0.8$

- FURTHER ASSUME THAT H(THE HALF-RANGE OF THE RIDGE HEIGHTS) IS 100m, AND THAT λ, THE SPACING BETWEEN RIDGE CRESTS IS 1500m

- THE COSINE OF ARCSIN(0.8) IS 0.600, AND AIR DENSITY AT THE ALTITUDE OF YUCCA MOUNTAIN IS ABOUT 1 kg/CUBIC METER. HENCE,

  $\Delta P = 0.13U^2$

COMPARISON OF TEMPERATURE-DEPENDENT AND WIND-DEPENDENT FLOWS IN WELL UZ6S, BASED ON THE THEORETICAL WIND-GENERATED PRESSURE POTENTIAL

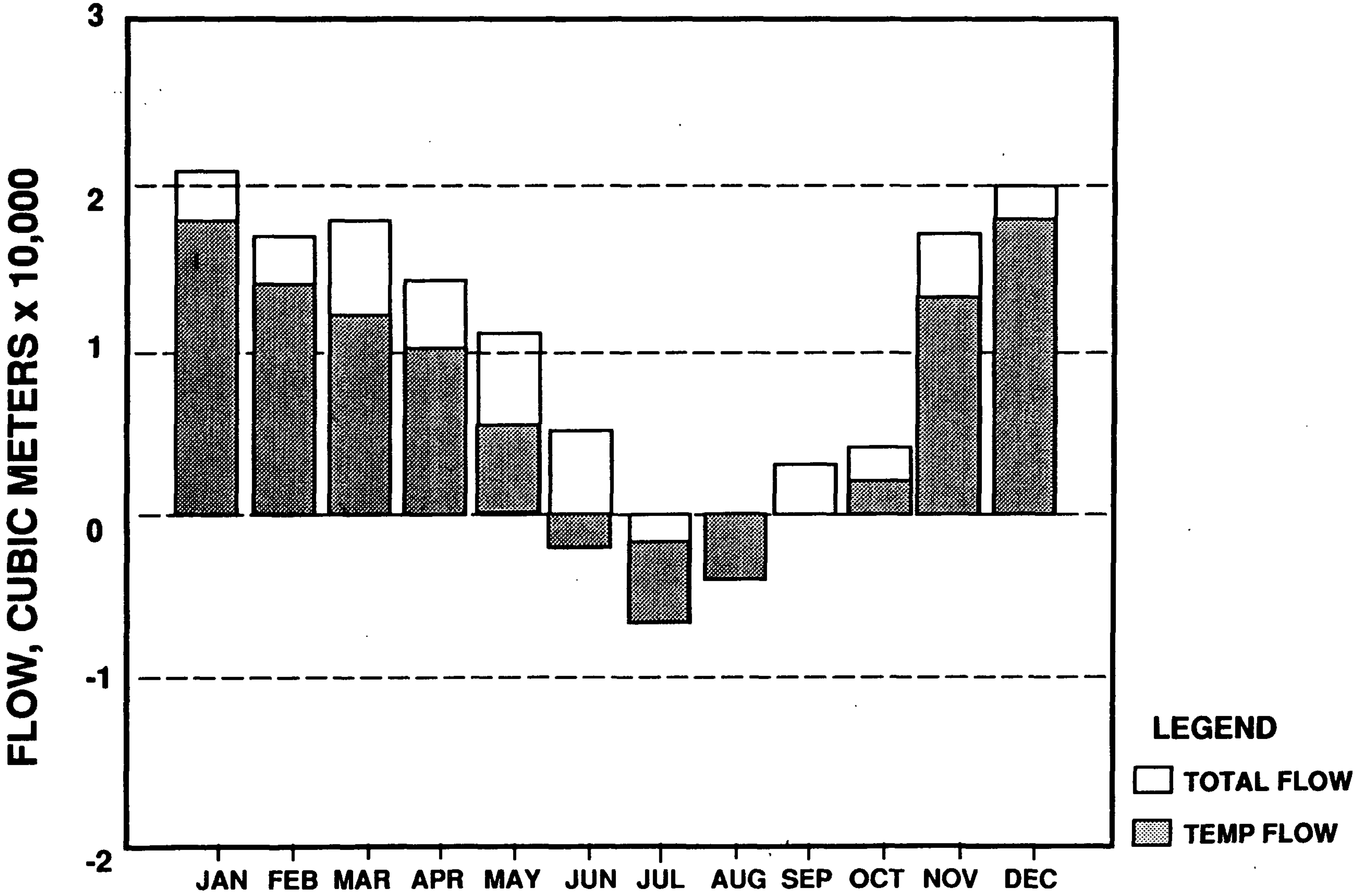
(CONTINUED)

- **FROM THE FLOW RESPONSE OF WELL UZ6S TO THE TEMPERATURE-BASED ΔP, FLOW VELOCITY $V = 0.3\Delta P$**

  HENCE, $V_W = .04U^2$ AND THE THEORETICAL MAXIMUM WIND-INFLUENCE FUNCTION IS .04

- **THIS THEORETICAL VALUE COMPARES WITH REGRESSION-BASED ESTIMATES FOR THE WIND INFLUENCE FUNCTION OF 0.05 FOR WEST WINDS AND 0.03 FOR EAST WINDS - AGREEMENT THAT IS QUITE GOOD**

MONTHLY AIR FLOW FROM WELL UZ6S, 1988



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ANNUAL FLOW SUMMARY FOR WELL UZ6S, 1988 - PREDICTED IN ABSENSE OF WELL LOSSES

TEMPERATURE-BASED	1,400,000 KG
WIND-BASED	600,000 KG
TOTAL FLOW	2,000,000 KG

ANNUAL FLOW SUMMARY FOR WELL UZ6S, 1988 - WELL LOSSES INCLUDED

TEMPERATURE-BASED AIR FLUX	800,000 KG
WIND-BASED AIR FLUX	500,000 KG
TOTAL AIR FLUX	1,300,000 KG
NET WATER VAPOR FLUX	16,000 KG
NET FLUX OF CARBON AS CO_2	490 KG

SUMMARY

- EFFECTS OF VARIATION IN BAROMETRIC PRESSURE, DIFFERENCES BETWEEN AIR AND ROCK GAS TEMPERATURE, AND WIND ALL RESULT IN SIGNIFICANT AIR CIRCULATION THROUGH YUCCA MOUNTAIN, AT LEAST IN THE PRESENCE OF OPEN BOREHOLES. HOWEVER, ONLY TEMPERATURE AND WIND EFFECTS RESULT IN SUBSTANTIAL NET CIRCULATION THROUGH THE MOUNTAIN

- ANALYSIS OF DATA FROM WELL UZ6S INDICATES THAT, IN THE ABSENSE OF NONLINEAR EFFECTS DUE TO TURBULENT FLOW, TEMPERATURE EFFECTS WOULD GENERATE ABOUT 70 PER CENT OF THE NATURAL CIRCULATION, AND WIND EFFECTS ABOUT 30 PER CENT

SUMMARY

(CONTINUED)

- NEARLY 40 PER CENT OF THE ACTUAL FLOW FROM WLL UZ6S IS GENERATED BY WIND EFFECTS, DUE TO THE ATTENUATION OF HIGH TEMPERATURE-INDUCED WINTERTIME FLOW VELOCITIES BY FRICTION LOSSES IN THE WELL BORE

- DESPITE THE FACT THAT AT LEAST 5,000,000 CUBIC METERS NET EXHAUST OF ROCK GAS HAS OCCURRED FROM WELL UZ6S DURING THE PERIODS THE WELL HAS BEEN UNCAPPED SINCE SEPTEMBER 1986, LITTLE OR NO CHANGE HAS OCCURRED IN THE ROCK GAS CHEMISTRY

CONCLUSION

- THE HIGHLY FRACTURED WELDED TUFFS COMPRISING YUCCA MOUNTAIN ARE SUBJECT TO SUBSTANTIAL AIR CIRCULATION, DUE BOTH TO TEMPERATURE AND TO WIND EFFECTS
  - AIR CIRCULATION MAY BE OF SIGNIFICANCE BOTH IN SPEEDING THE RELEASE OF GASEOUS RADIONUCLIDES FROM THE PROPOSED NUCLEAR-WASTE REPOSITORY, AND BY INCREASING THE VAPOR DISCHARGE FROM THE MOUNTAIN, THUS LIMITING DEEP PERCOLATION THROUGH THE MOUNTAIN