BOREHOLE IMAGING AND VISUALIZATION OF FRACTURED-BEDROCK AQUIFERS

• This presentation focuses on optical borehole imaging of water wells and the hydrogeological framework of fractured bedrock aquifers in New Jersey. A review will be given of some approaches and methods of interpretation, cataloguing, and visualization of surface and subsurface data, and why it is important to use stratigraphic and structural principles when interpreting borehole image logs.

•Review the tools, approaches, and results of studies by the NJGS from 2000-2010

• Show the new tools and approaches currently used by the NJGWS 2011 -

• Compare the results of 2nd and 3rd generation technology

• Show and example of interpreting borehole imagery w/o proper geological treatment

• Briefly review some 3D visualization methods for geological structures using GIS and Google Earth

Geological Research & Support Section of the Bureau of Water and Geoscience

2 Licensed well drillers, 3 PhDs, Spayd jobs, and the good faith of the State of New Jersey.

Mount Sopris, Inc.
geophysical logging suites (1986 -)

1978 Gearhart-Owens (WITCO) analog logger, caliper, gamma with casing-collar locator, fluid temp/electrical, propeller flowmeter, and depth sampler ($25,000)

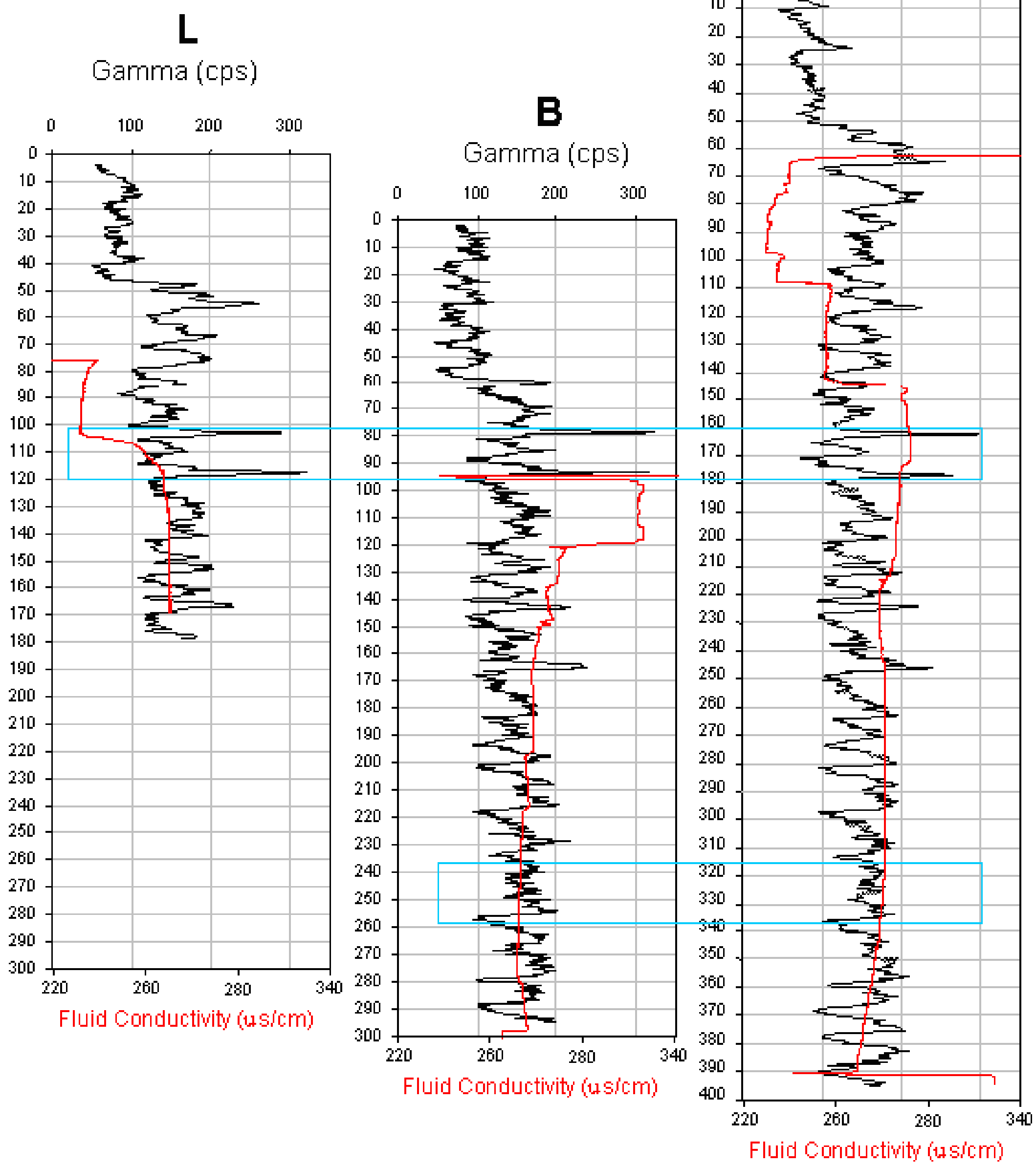
1986 Mt. Sopris Series 3 (1rst digital logger) , recorded on 9-track tapes including a 9’ sonic probe, a neutron probe, gamma (~250K)

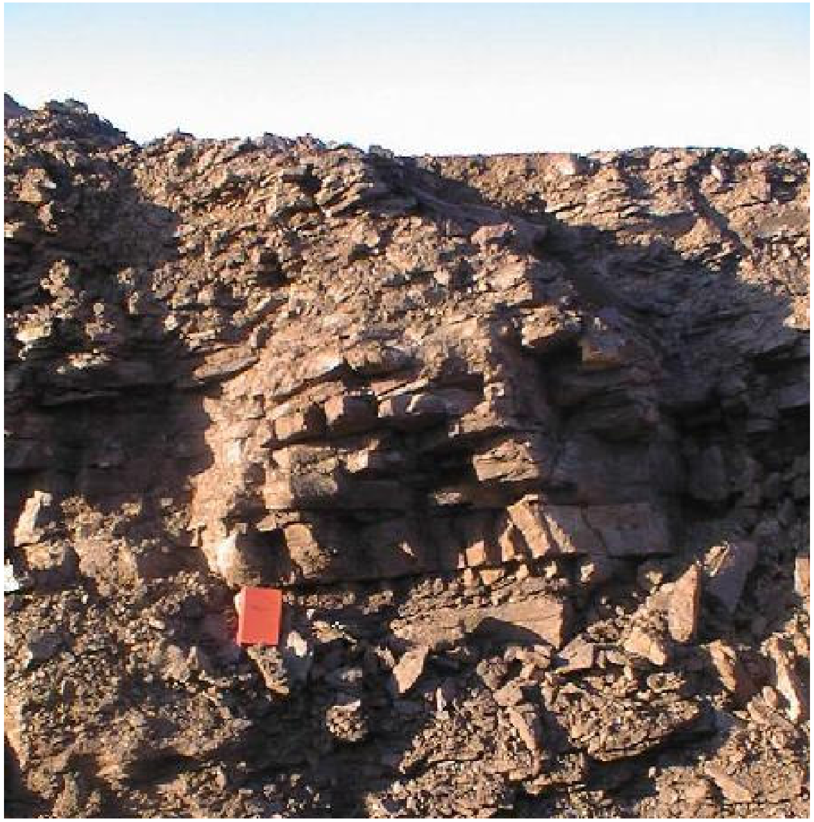
1995 – 2000 MT Sopris MGXII System (~$50,000) 800-meter winch 1/10” single-conductor, gamma w/ long-short normal (polytool 10K), caliper, fluid-temp/electrical tool, Geonics EM39 tool (useful for logging in PVC and detecting plumes, conductive fill, etc.) WellCAD added more recently.

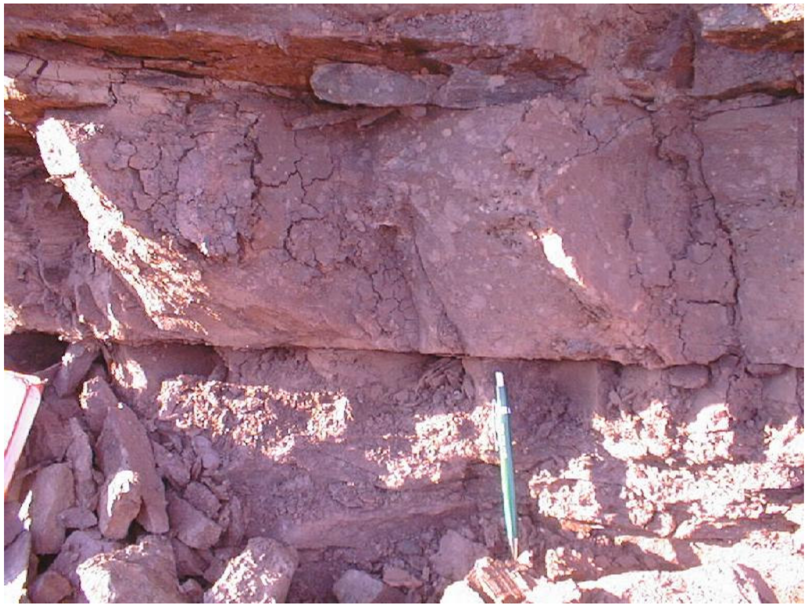
Deepest wells NBCP wells (~4000’),

Coastal Plain wells <700 ft bls

STRATIGRAPHIC CORRELATION BASED ON GAMMA BOREHOLE LOGS AND COMPARISON OF FLUID CONDUCTIVITY PROFILES FOR THE 6" MONITORING AND DOMESTIC WATER-SUPPLY WELLS AT THE HERON GLEN GOLF COURSE, RARITAN TWP., HUNTERDON COUNTY, NEW JERSEY, N.J. GEOLOGICAL SURVEY, G.C. HERMAN, 2004 FEBRUARY 3





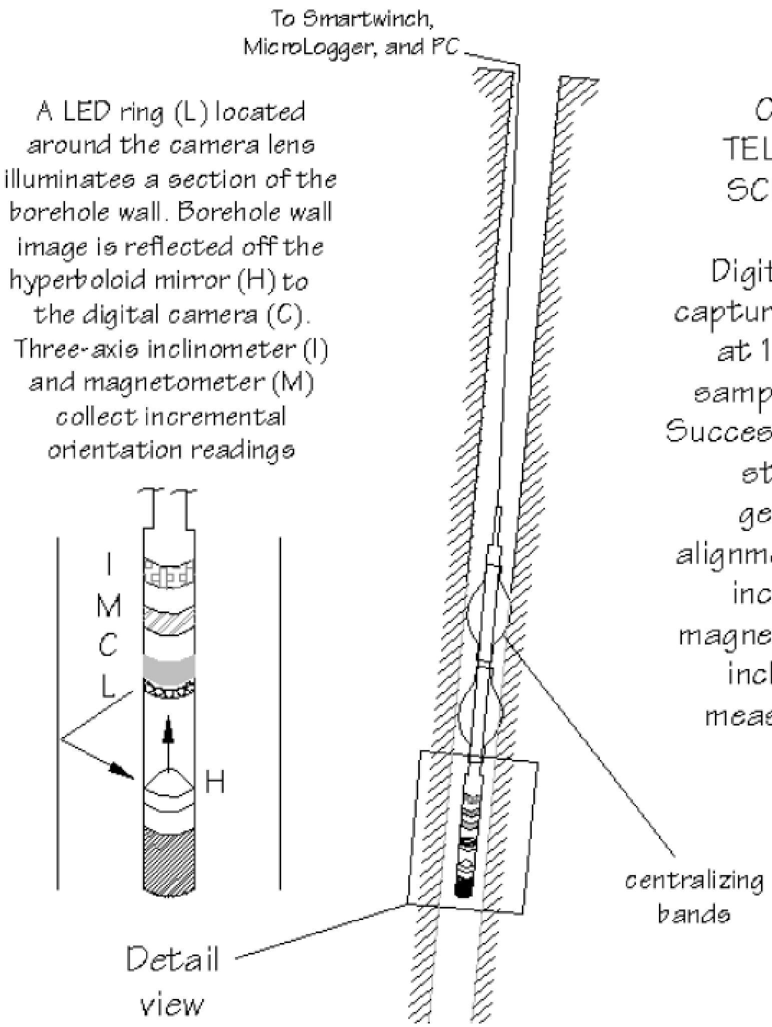


Robertson Geologging Ltd.System 2002-2010

Portable Smartwinch w/ 300 m coax cable
Fluid temp and electrical conductivity
Multi-directional Color TV camera (VHS)
Optical Televiewer (OPTV)
Heat Pulse Flowmeter

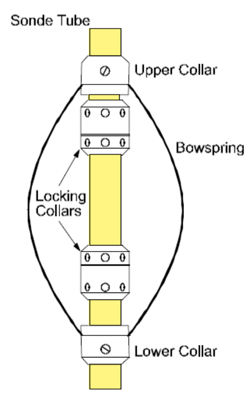
DOPTV

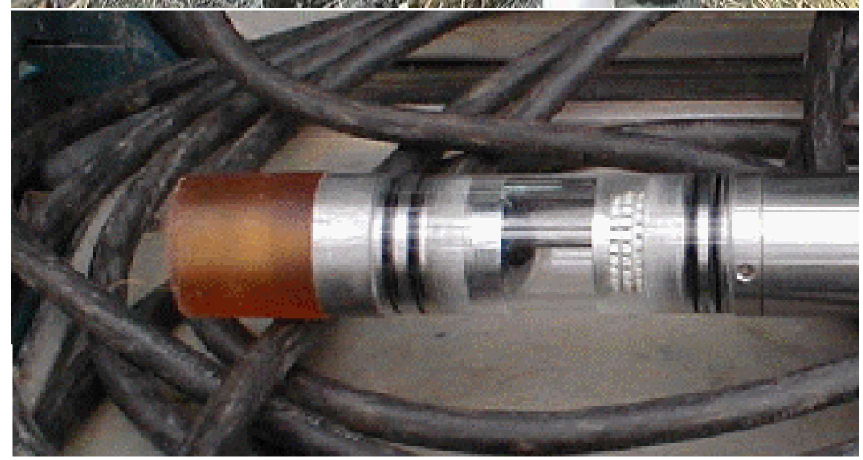
DIGITAL OPTICAL TELE-VIEWER

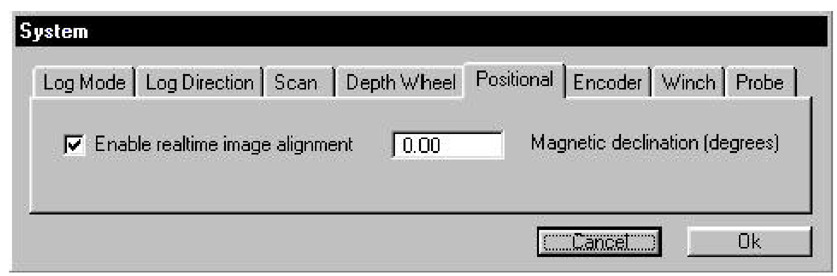


OPTICAL TELEVIEWER SCHEMATIC

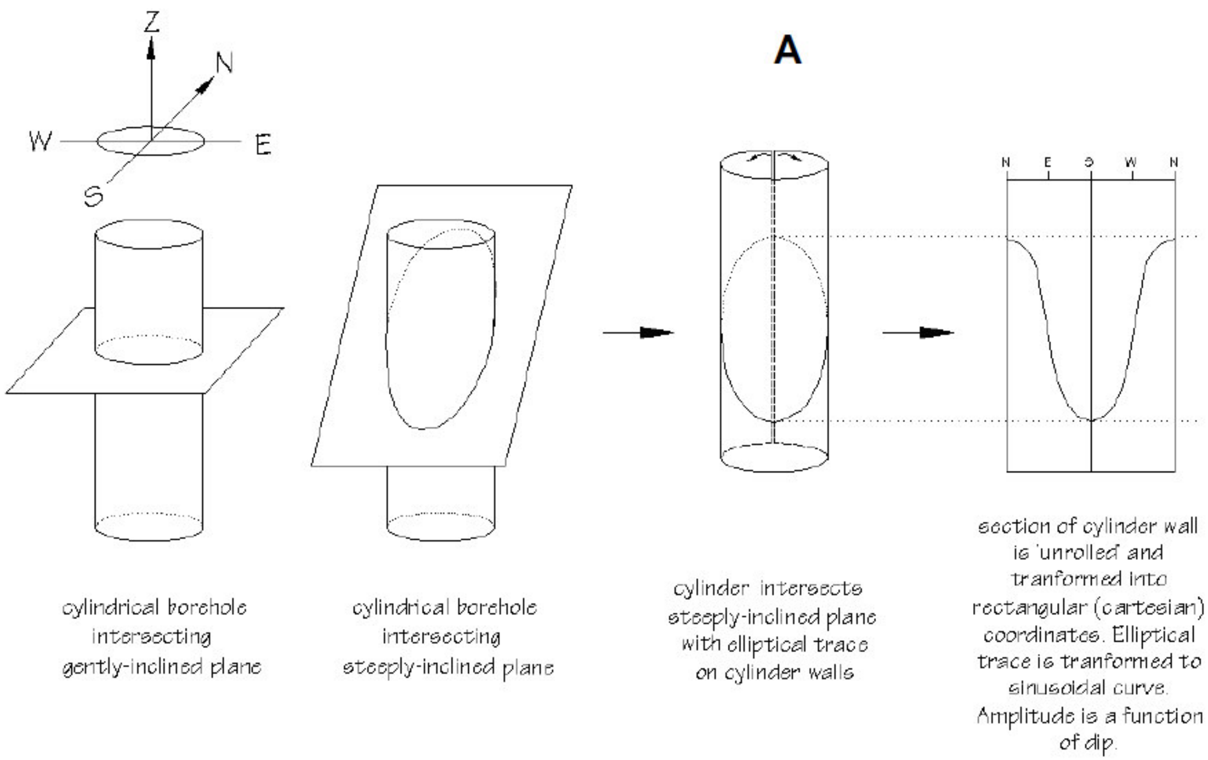
Digital camera captures 360° ring at 1mm-depth sample intervals. Successive rings are stacked in geographic alignment based on incremental magnetometer and inclinometer measurements.



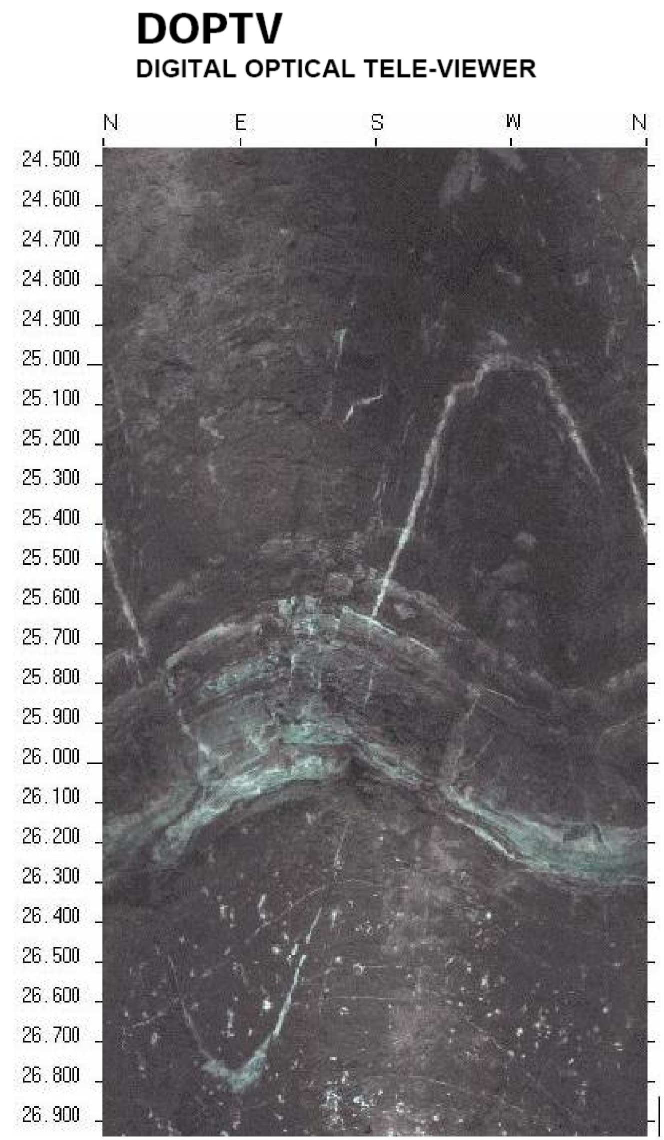




OPTV scans of 360 or 720 pixels per 1mm scan ring


A
Z
N
W
E
S
N E S W N
cylindrical borehole intersecting gently-inclined plane
cylindrical borehole intersecting steeply-inclined plane
cylinder intersects steeply-inclined plane with elliptical trace on cylinder walls
section of cylinder wall is 'unrolled' and tranformed into rectangular (cartesian) coordinates. Elliptical trace is tranformed to sinusoidal curve. Amplitude is a function of dip.


About OPTV
ROBERTSON GEOLOGGING LIMITED
OPTV (c)
Optical Televiewer
Version 107 24-11-99
OK


DOPTV
DIGITAL OPTICAL TELE-VIEWER
N
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24.500
24.600
24.700
24.800
24.900
25.000
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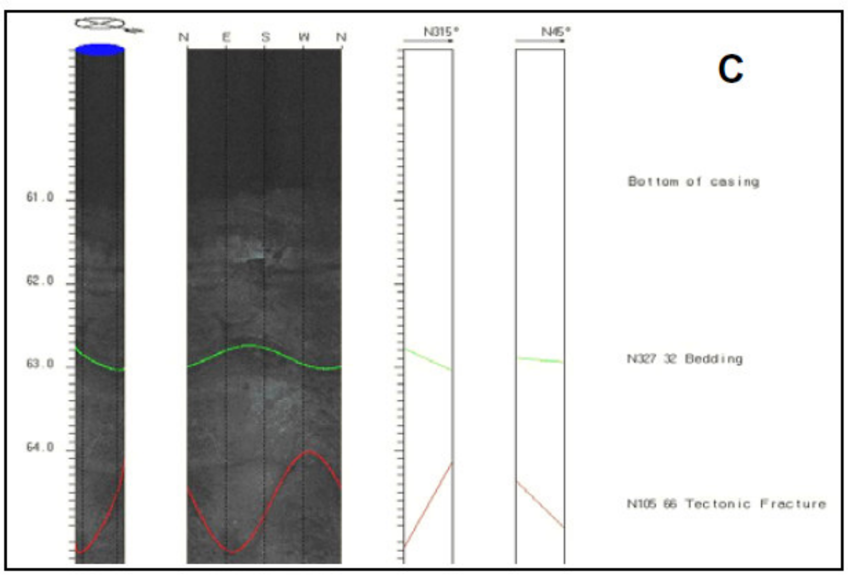
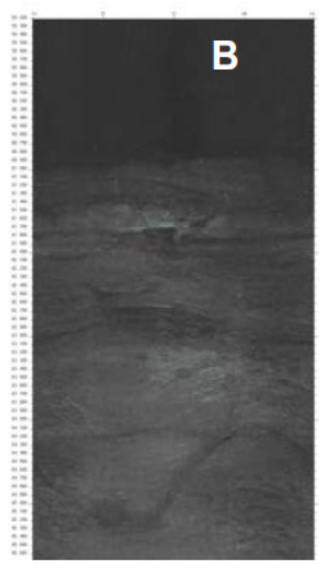
26.900


C
N E S W N
N315°
N45°
61.0
62.0
63.0
64.0
Bottom of casing
N327 32 Bedding
N105 66 Tectonic Fracture


B

Borehole Imaging Review

Borehole imaging tools developed from industry's need for borehole inspection devices, for fracture detection and for use in well remediation.

source: Lowell, M.A., Williamson,, G., & Harvey, P.K., (eds) 1999, Borehole Imaging: applications and case histories. Geological Society of London Special Publication 159, 1-43.

- **First devices introduced in the 1950's with rigged photographic cameras.**
- **Downhole TV introduced in the 1960's.**
- **First acoustic borehole televiewer's in the late 1960's, resistivity shortly after**
- **First generation optical imaging, including the Raax BIPS system, late 1980s and early 1990's.**
- **Second generation microresistivity and high-resolution devices late 1990 to mid 2000's.**
- **Mid 2000's on, the third generation devices have increased logging speed from increased computing power, electronic refinements, and more data processing capabilities….**

Borehole Imaging Review

2008 World Stress Map Project
Guidelines: Image Logs

Borehole breakout and drilling-induced fracture analysis from image logs

M. Tingay, J. Reinecker, and B. Müller

Sonic logs

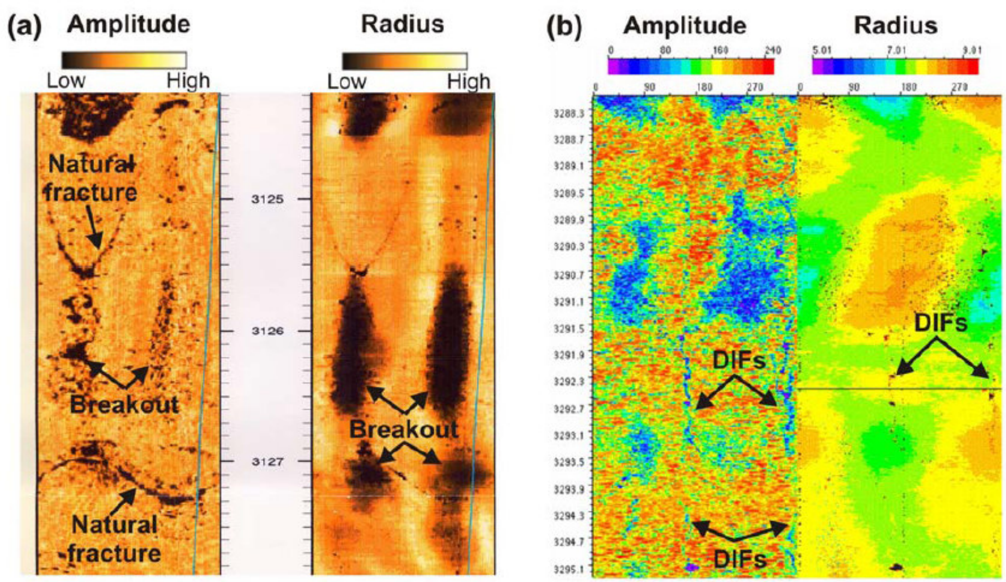
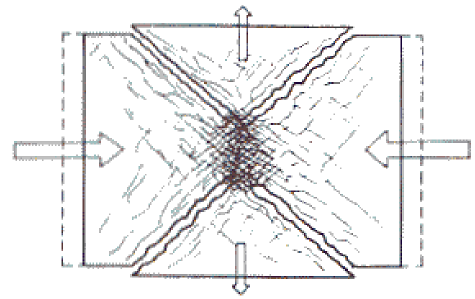
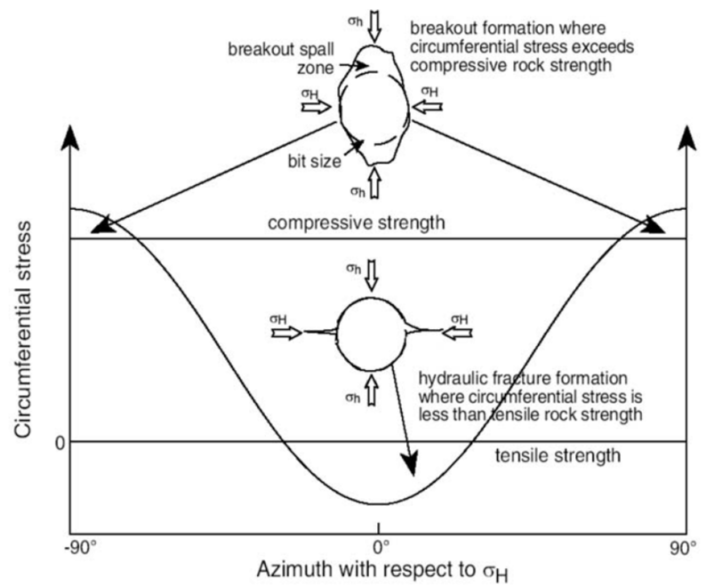


Figure 4: Example of breakouts and drilling-induced fractures (DIFs) observed on acoustic image logs. (a) Borehole breakouts observed on Ultrasonic Borehole Imager log. Borehole breakouts are broad zones of high borehole radius and, to a lesser extent, low reflection amplitude oriented towards 095-275°N. The borehole breakouts indicate that the present-day maximum horizontal stress is oriented approximately N-S. (b) Borehole Televiewer log showing DIFs oriented towards 165-345°N. DIFs are observed as zones of low amplitude (left image) and, to a lesser extent, higher radius (right image). The DIFs indicate that the present-day maximum horizontal stress is oriented approximately SSE-NNW.



B Conjugate shear fractures in 'brittle' rock (after L. Müller, 1963; reprinted by permission of Ferdinand Enke Verlag). Angle between rupture surfaces remains preserved during shortening; accommodation of shortening by brecciation and dilatation.

Mechanics of tectonic faulting, G. Mandl, 1988, Elsevier



Borehole Imaging Review

Journal of Applied Geophysics
Volume 55, Issues 1–2, January 2004, Pages 151–159
Non-Petroleum Applications of Borehole Geophysics

Acoustic and optical borehole-wall imaging for fractured-rock aquifer studies

John H. Williams [a], Carole D. Johnson [b]
[a] U.S. Geological Survey, 425 Jordan Road, Troy, NY, 12180, USA
[b] U.S. Geological Survey, 11 Sherman Place, Storrs, CT, 06269 USA

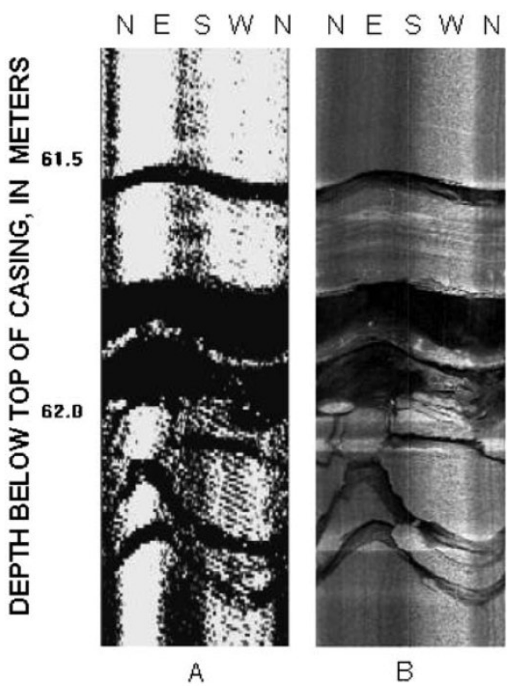
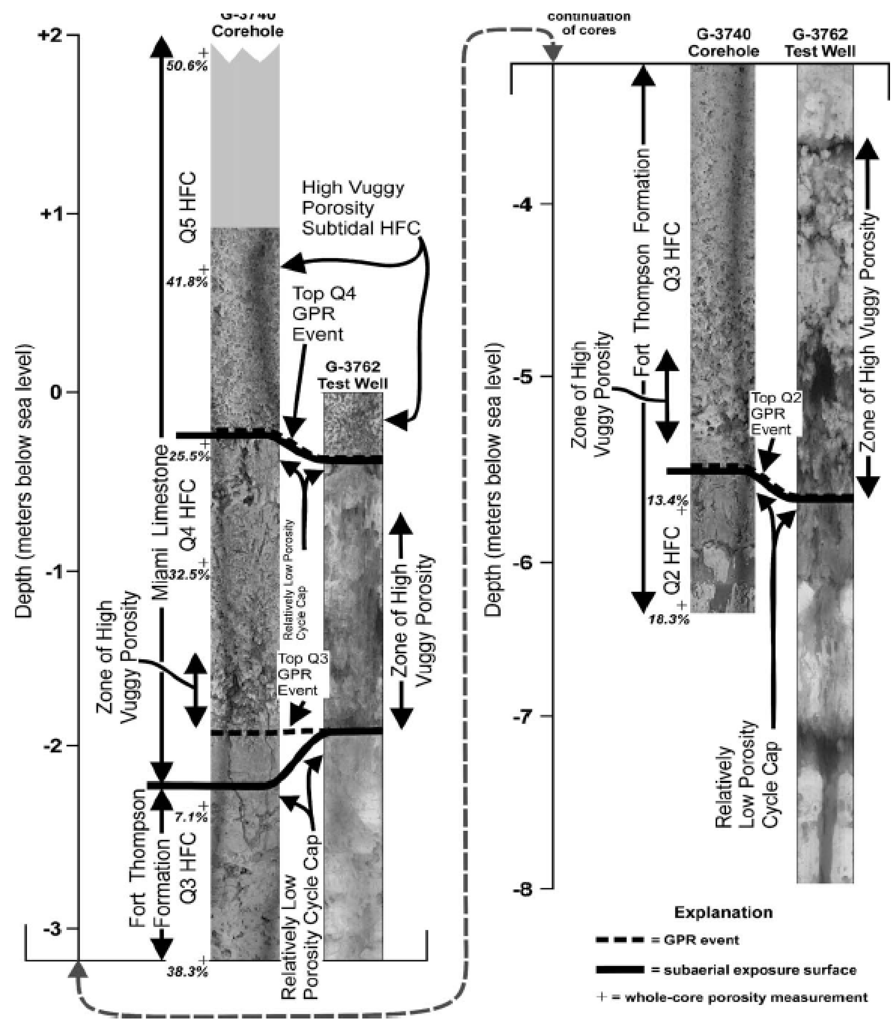


Fig. 9. Televiewer images of a 75-mm diameter borehole completed in sandstone: (A) acoustic; (B) optical (Williams et al., 2002).

ELSEVIER
Available online at www.sciencedirect.com
SCIENCE DIRECT
Journal of Applied Geophysics 55 (2004) 61–76
Journal of Applied Geophysics
www.elsevier.com/locate/jappgeo

Application of ground-penetrating radar, digital optical borehole images, and cores for characterization of porosity hydraulic conductivity and paleokarst in the Biscayne aquifer, southeastern Florida, USA☆

Kevin J. Cunningham*
U.S. Geological Survey, Water Resources Discipline, 9100 NW 36th Street, Suite 107, Miami, FL 33178, USA



Example of RG OPTV results

Wells 95 and 96 - Brunswick lower red zone

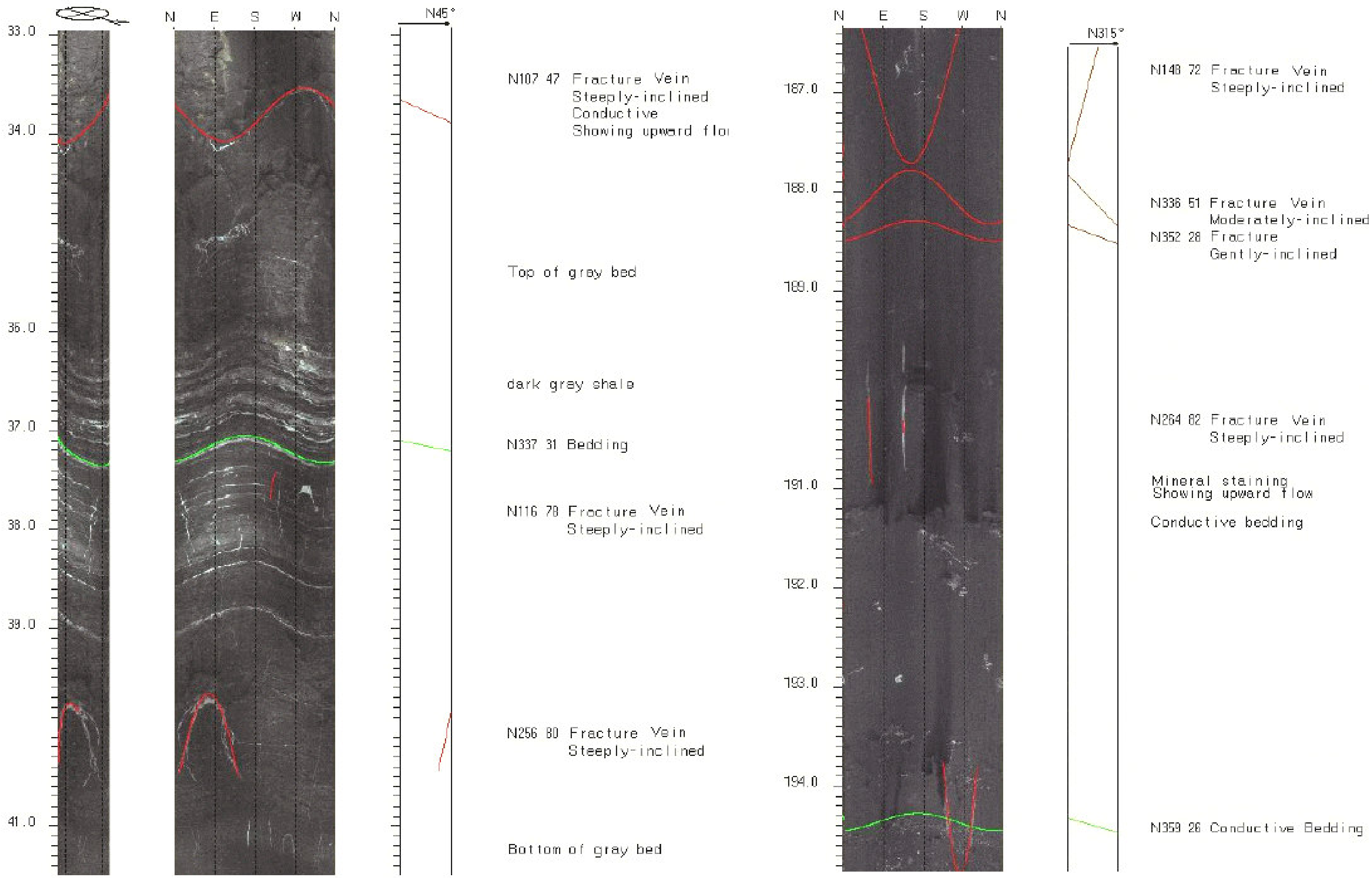


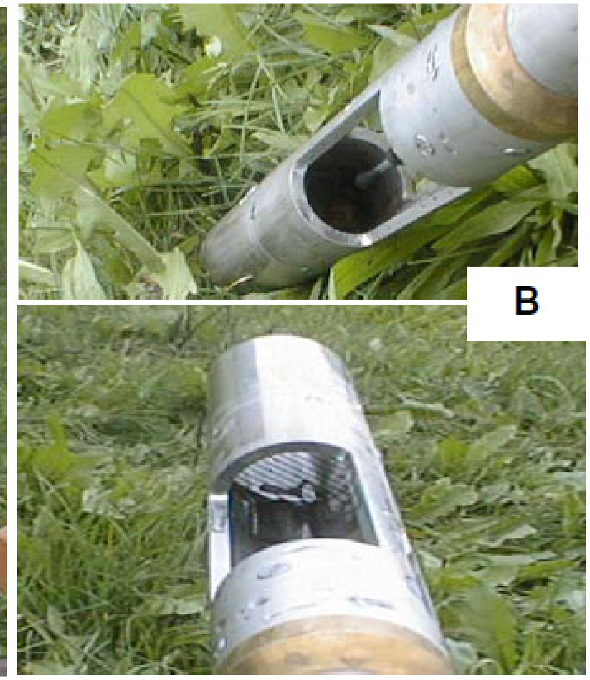
FIGURE 3M12. OPTV records of 6-inch diameter wells 95 (left) and 96 (right) at the Stony Brook-Millstone Watershed Association well field showing geologic structures and hydraulically-conductive features in red and gray mudstone and gray shale. Depth values are in feet below land surface.

RG

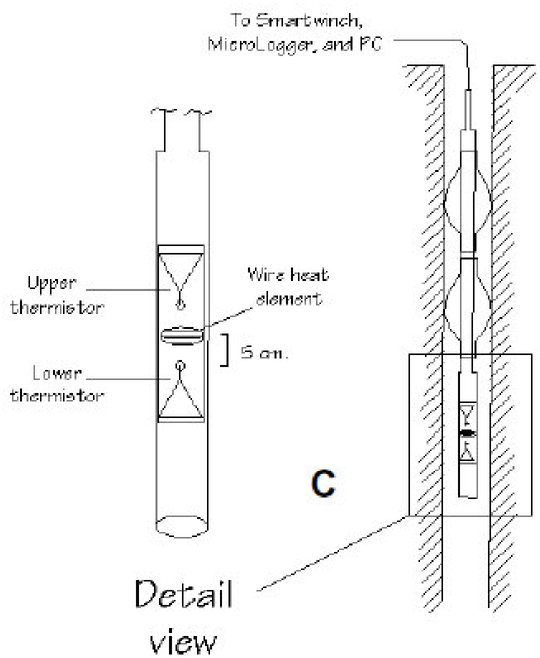
HEAT-PULSE FLOW METER

(HPFM)

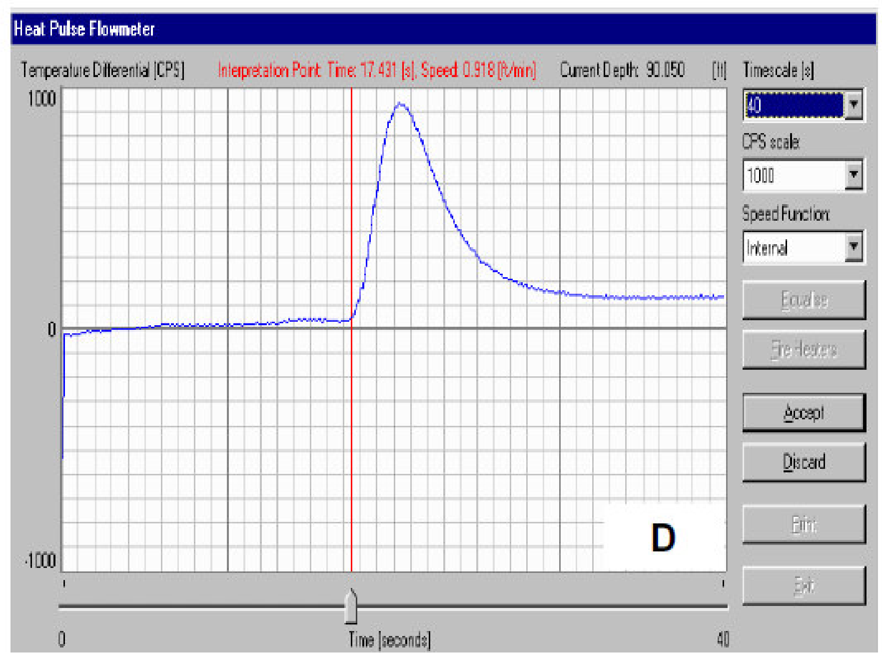
A



B



C



D

New Jersey Geological Survey

Technical Memorandum TM 06-1

Field Tests Using a Heat-Pulse Flow Meter to Determine its Accuracy for Flow Measurements in Bedrock Wells

ABSTRACT

The accuracy of water-flow measurements taken with a heat-pulse flow meter (HPFM) in 4-inch and 6-inch-diameter water wells was evaluated in four field tests. The tests are based on comparing fluid velocities induced through pumping and measured at the discharge point with a digital flow meter with fluid velocities in the borehole measured with the HPFM. Two of the tests

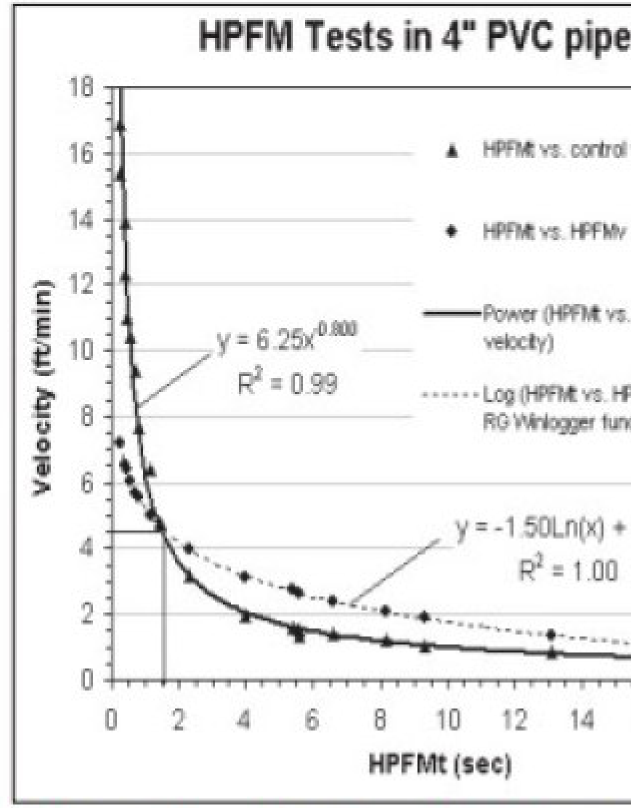


Figure 4a. Two mathematical relationships are ch
Tests 1 and 2 based on fixed, upward-directed flow
0.5 ft/min and 18.0 ft/min in a 4-inch PVC pipe. Th
line charts the logarithmic function used by RG
ware to convert heat-pulse response times (HPF
locities (HPFMv). The solid trend line charts the
derived from tests 1 and 2 that accurately defines
between HPFMt for the total range of flow velocit
son of the two curves shows that they cross at
response time. This indicates that the RG Winlog

NJGS Robertson Geologging system acquired and deployed 2002-2009

Obtained with research funding from the NJDEP Hazardous Waste Spill Fund

RG system:

OPTV	30,500
70mm VHS multidirectional camera	21,725
Smartwinch	9,875
RG Micrologger	9,400
HPFM	6,950
FT&C probe	3,800
Ruggedized PC	2,975
RGLDIP	400

TOTAL ~ $100K

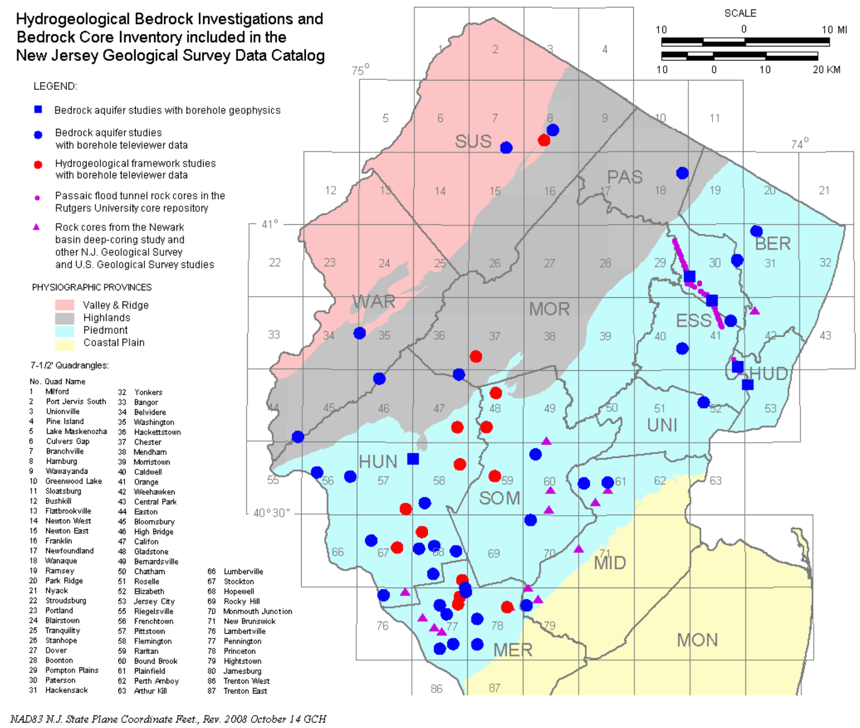
w/O vehicle

New Jersey Geological Survey

Bulletin 77

Contributions to the Geology and Hydrogeology of the Newark Basin

State of New Jersey
Department of Environmental Protection
Water Resource Management
New Jersey Geological Survey
2010



Over 50 sites with over 200 wells

Click on the links below for details:

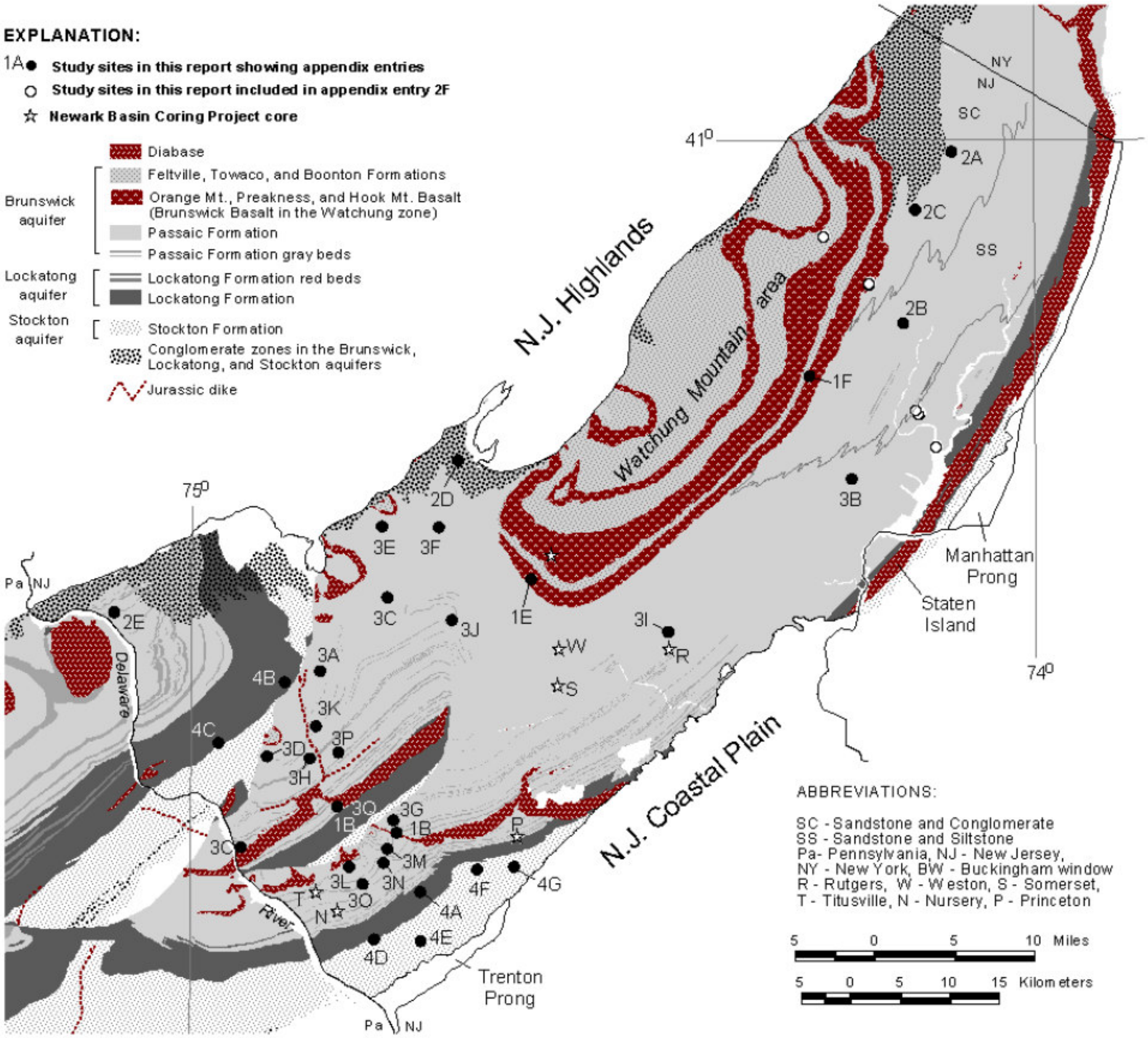
Bedrock Aquifer Investigations IMAGE

New Jersey Geological Survey
Geodata Catalog

County Index:

- **Bergen County**
  - Interpretation of Opitcal Televiewer data for the Passaic Formation near the Shell Service Station, 657 Franklin Turnpike, Ridgewood Boro
  - Interpretation of Optical Televiewer data for the Passaic Formation at the Sandoz Chemical Corporation, Fairlawn Ave & 3rd St., Fairlawn Borough
- **Essex County**
  - Bedrock Aquifer Study of the Orange Mt. Basalt and Passaic Formation from the Water Wells at the Essex County Country Club, West Orange Twp.
  - Bedrock Aquifer Study of the Passaic Formation near the Hoffmann La Roche facility, Clifton City and Nutley Twp.
  - Geotechnical Studies of the Orange Mt. Basalt and Passaic Formation from the Passaic Flood Tunnel Project, Passaic and Essex Counties
- **Hunterdon County**
  - Bedrock Aquifer Study of Jurassic Diabase from a Domestic Well, 258 S. Franklin St., Lambertville

The NJ-NY parts of the Newark basin



Borehole Geophysics and Hydrogeology Studies in the Newark Basin, New Jersey

By Gregory C. Herman and John F. Curran, N.J. Geological Survey

Appendixes 1 to 4 of

Contributions to the Geology and Hydrogeology of the Newark Basin

N.J. Geological Survey Bulletin 77

State of New Jersey
Department of Environmental Protection
Water Resource Management
New Jersey Geological Survey
2010

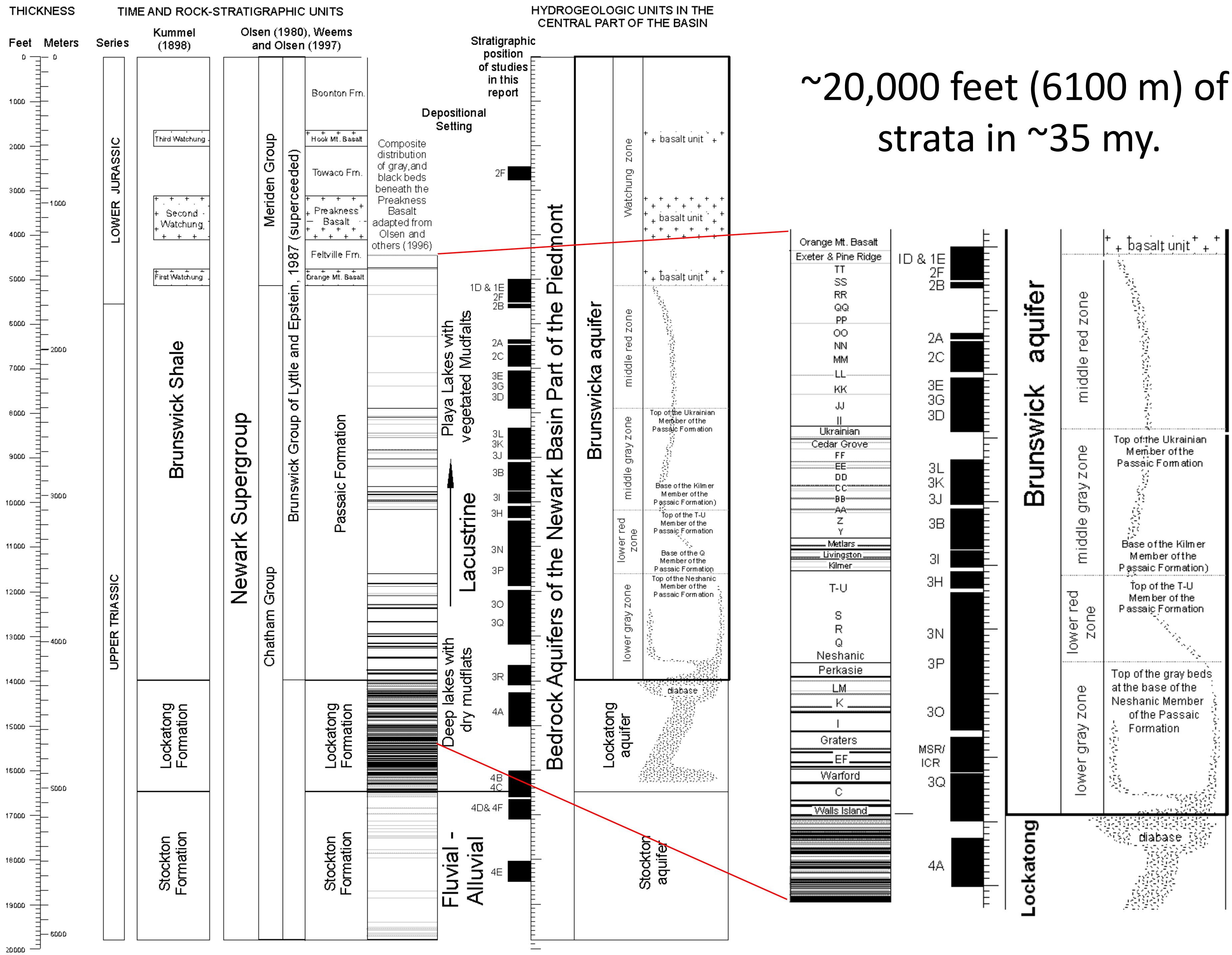
TABLE AP1. RECORDS OF WELLS AND CORES IN THE NEWARK BASIN, NEW JERSEY INCLUDED IN APPENDIXES 1 TO 4

Well	Appendix Entry	NJGS Project	Project Identification or Location	Diameter (inches)	Well Type	Log Source	Aquifer or Aquifer Zone
1	1A	258 S. Franklin St.AGW	258 S. Franklin St.	6	Domestic	NJGS	Diabase
2	1B	Snydertown Rd. AGW	SR65	6	Domestic	NJGS	Diabase
3	1B	Snydertown Rd. AGW	SR66	6	Domestic	NJGS	Diabase overlying Brunswick lower gray
4	1B	Snydertown Rd. AGW	SR69	6	Domestic	NJGS	Diabase
5	1B	Snydertown Rd. AGW	SR98	6	Domestic	NJGS	Diabase
6	1C	Crusher Rd. WS	Crusher Rd.	6	Domestic	NJGS	Diabase
7	1D	East Amwell WS	Block 38, Lot 16	6	Domestic	NJGS	Diabase
8	1E	Essex County Country Club WS	Well 1	8	Irrigation	NJGS	Brunswick Watchung basalt and middle red
9	1E	Essex County Country Club WS	Well 2	8	Irrigation	NJGS	Brunswick Watchung basalt and middle red
10	1E	Essex County Country Club WS	Well 3	8	Irrigation	NJGS	Brunswick Watchung basalt and middle red
11	1F	1163 Delaware AGW	1163 Delaware Ave	6	Domestic	NJGS	Brunswick Watchung basalt and middle red
12	2A	Ridgewood Shell GWI	MW-9D	6	Monitoring	DEP/SRP	Brunswick sandstone conglomerate
13	2A	Ridgewood Shell GWI	MW-27	6	Monitoring	DEP/SRP	Brunswick sandstone conglomerate
14	2A	Ridgewood Shell GWI	MW-29	6	Monitoring	DEP/SRP	Brunswick sandstone conglomerate
15	2A	Ridgewood Shell GWI	MW-30	6	Monitoring	DEP/SRP	Brunswick sandstone conglomerate

TABLE AP1. (continued)

County	Municipality	USGS 7-1/2' Quadrangle	XY Source	GEOGRAPHIC (degrees) Latitude	Longitude	NAD83 NJSPF X_coord	Y_coord	NGVD88 Land elev (ft)	Elev. Source	Total Depth (ft)[1]	Casing (ft)[1]
Hunterdon	Lambertville	Lambertville, Pa-NJ	Map	39.8470978	74.2735330	369301.85	555707.65	269.53	DEM	370.0	48.5
Hunterdon	East Amwell	Hopewell, NJ	GPS	40.3973192	74.8244674	401759.26	569809.38	406.25	DEM	172.0	39.3
Hunterdon	East Amwell	Hopewell, NJ	GPS	40.3978303	74.8239106	401915.00	569995.00	409.20	DEM	591.0	46.1
Hunterdon	East Amwell	Hopewell, NJ	GPS	40.3975830	74.8255657	401453.71	569906.60	406.23	DEM	246.0	25.0
Hunterdon	East Amwell	Hopewell, NJ	GPS	40.3993800	74.8299300	400240.69	570565.72	376.00	DEM	283.0	30.0
Mercer	Hopewell	Pennington, NJ	Map	40.3739328	74.7575905	420360.00	561229.00	325.00	MAP	521.0	49.7
Hunterdon	East Amwell	Hopewell, NJ	GPS	40.4366880	74.7749039	415607.55	584103.74	490.00	DEM	493.5	45.1
Essex	West Orange	Orange, NJ	GPS	40.7829916	74.2647840	558141.67	710552.77	544.83	DEM	110.0	19.5
Essex	West Orange	Orange, NJ	GPS	40.7829916	74.2647840	557258.49	710226.32	516.82	DEM	317.4	17.9
Essex	West Orange	Orange, NJ	GPS	40.7842234	74.2618569	558067.82	710677.24	543.91	DEM	500.0	49.4
Somerset	Somerset	Bound Brook, NJ	Map	40.1084272	73.9533597	464880.00	645016.00	422.00	MAP	298.5	26.1
Bergen	Ridgewood	Hackensack, NJ	Map	40.9875499	74.0943230	604115.46	784920.77	108.25	DEM	84.4	26.7
Bergen	Ridgewood	Hackensack, NJ	Map	40.9869448	74.0940572	604189.86	784700.68	109.26	DEM	82.8	53.5
Bergen	Ridgewood	Hackensack, NJ	Map	40.9879161	74.0940012	604203.67	785054.62	108.93	DEM	67.8	47.9
Bergen	Ridgewood	Hackensack, NJ	Map	40.9875221	74.0948540	603968.92	784909.99	109.20	DEM	80.6	42.7

~20,000 feet (6100 m) of strata in ~35 my.



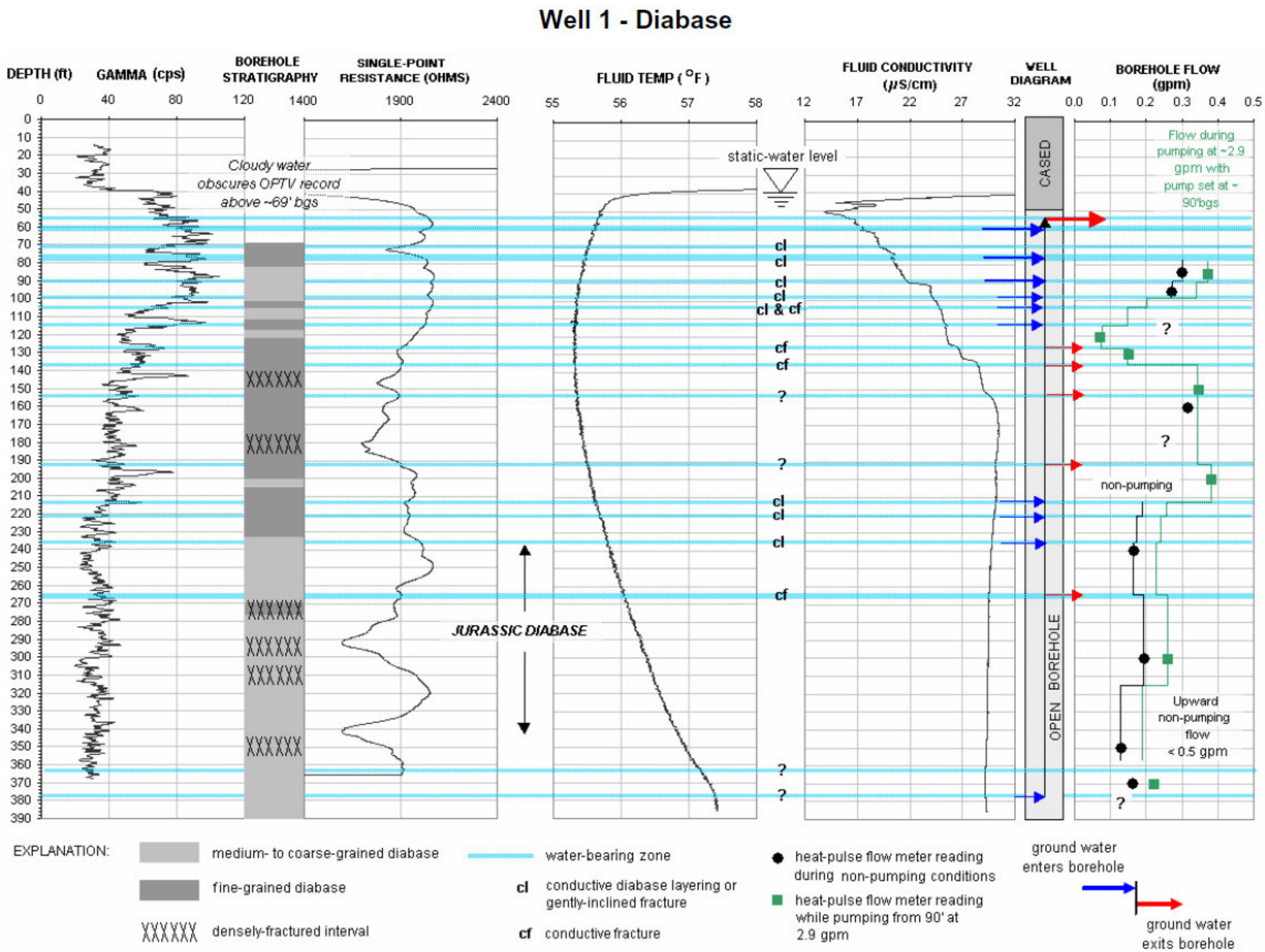


FIGURE 1A2. Hydrogeologic section based on geophysical logs for well 1 showing the vertical distribution and types of hydraulically-conductive features and water-bearing zones. Depth values are in feet below land surface.

Well 124 – Stockton sandstone

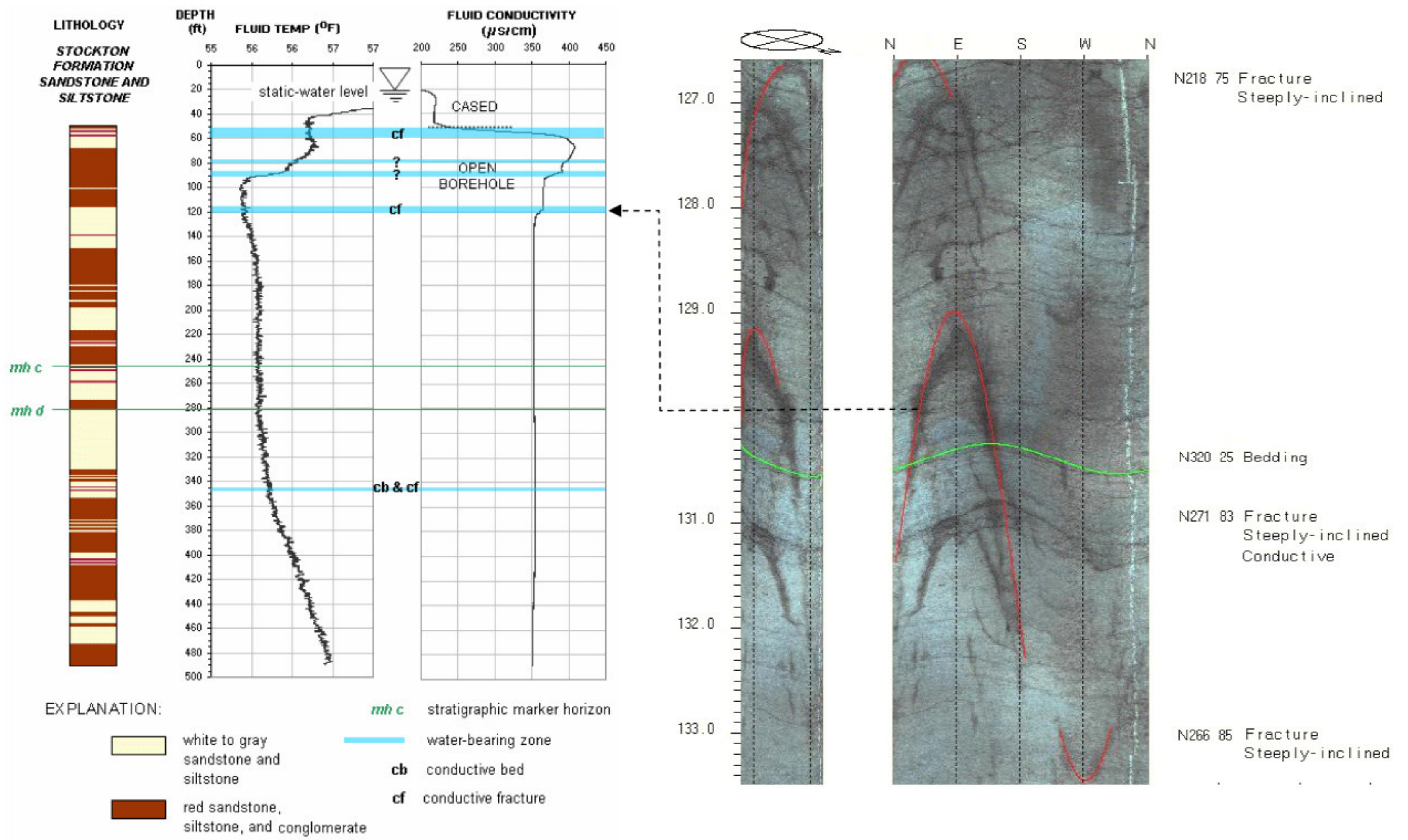


FIGURE 4F7. Hydrogeologic section based on geophysical logs (left) summarizing the distribution and types of hydraulically-conductive features in well 124 at the Springdale Golf Club, Princeton Twp., Mercer County, NJ. OPTV record of the 6-inch diameter well (right) shows geologic structures and hydraulically-conductive features in sandstone. Depth values are in feet below land surface.

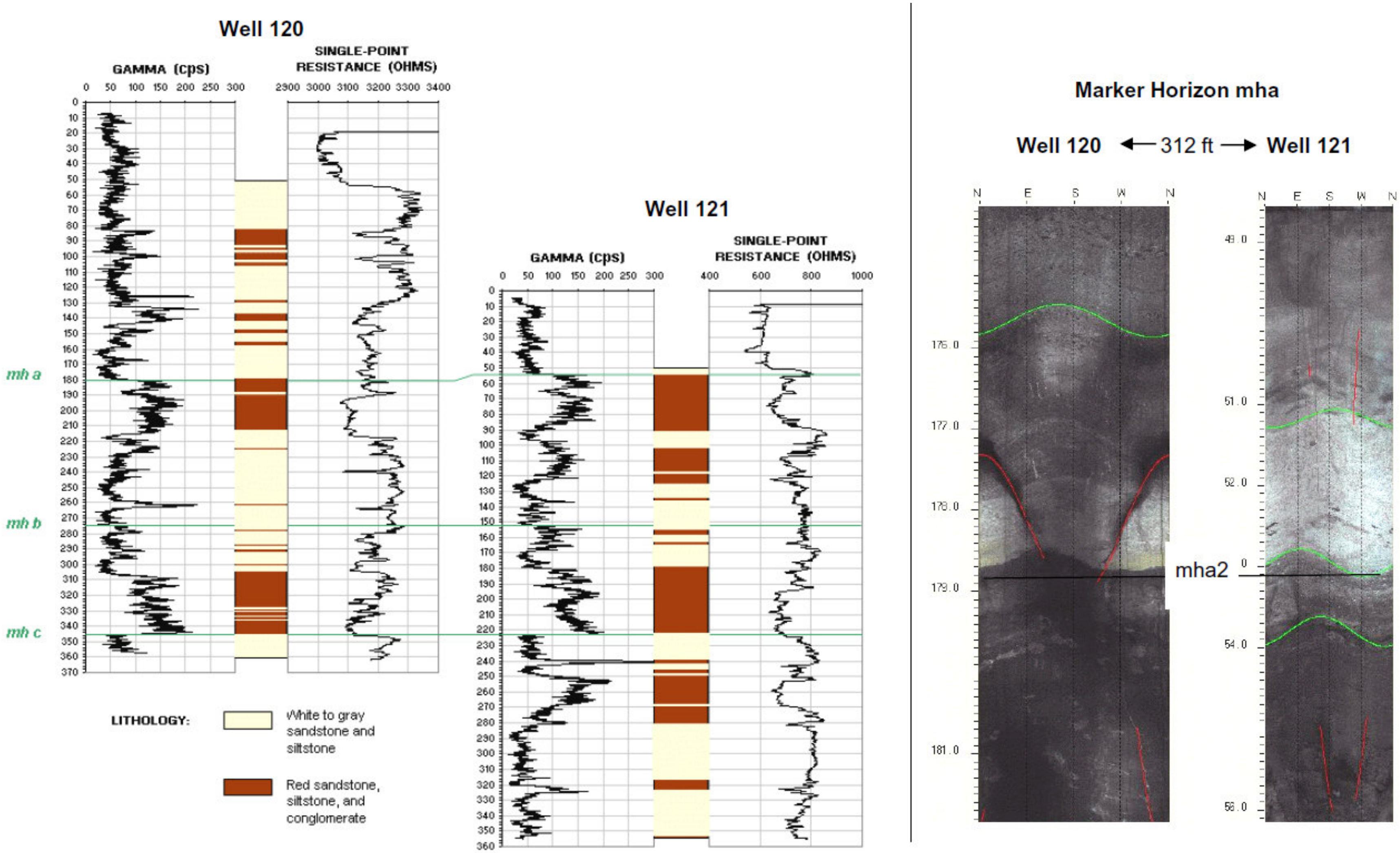


Figure 4E6. Stratigraphic correlation of wells 120 and 121 at the Greenacres Country Club, Rt. 206, Lawrence Twp., Mercer County, NJ based on natural gamma and electrical-resistivity logs (left) and OPTV records (right). Stratigraphic marker horizon mha is shown in both figures. Depth values are in feet below land surface.

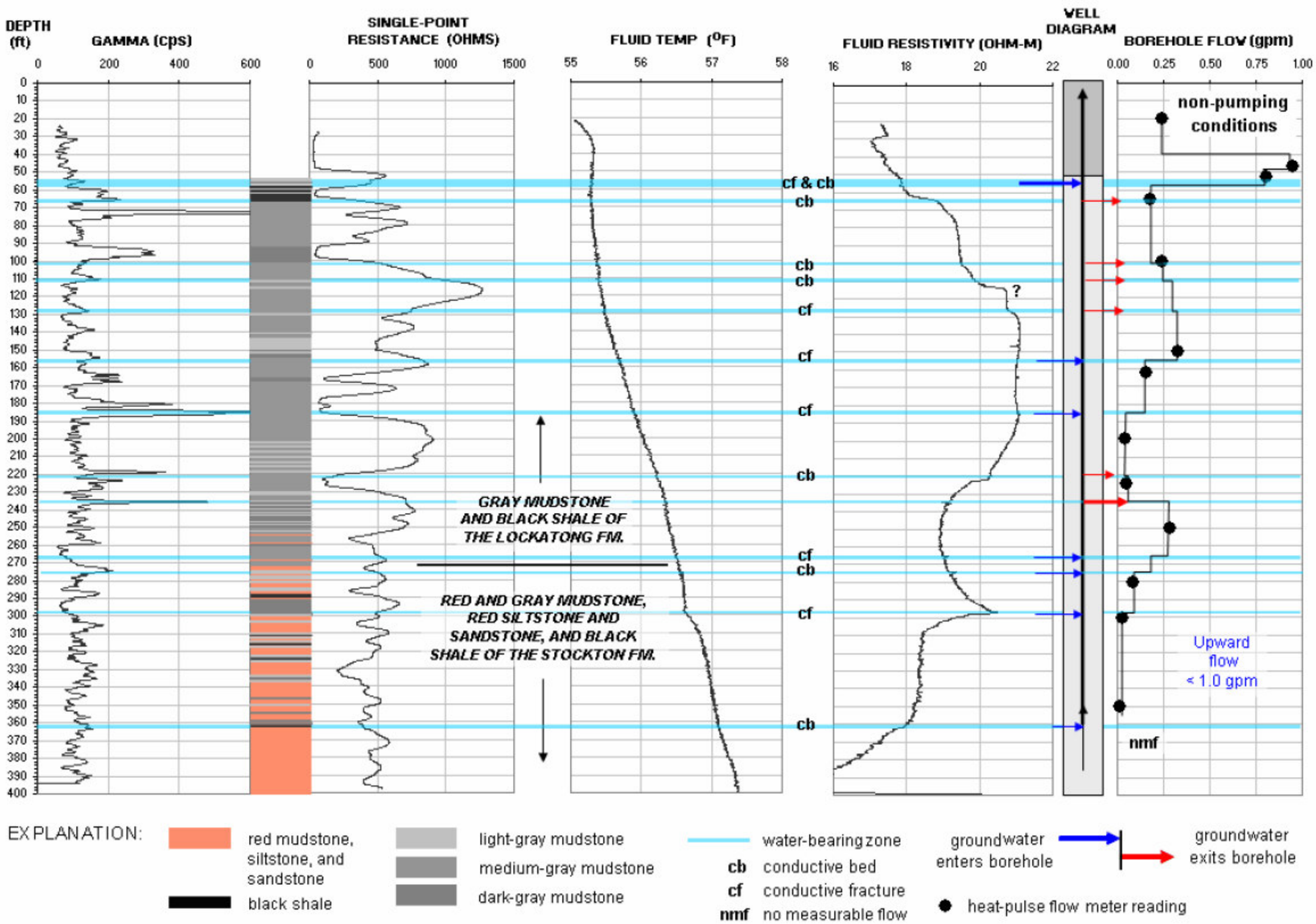


FIGURE 4C2. Hydrogeologic section based on geophysical logs for well 116 at Pine Hill Rd., Delaware Twp., Hunterdon County, NJ. The section shows the vertical distribution and types of hydraulically-conductive features and water-bearing zones in red and gray sandstone, siltstone and mudstone, and black shale. Depth values are in feet below land surface.

Well 105 - Brunswick lower gray zone

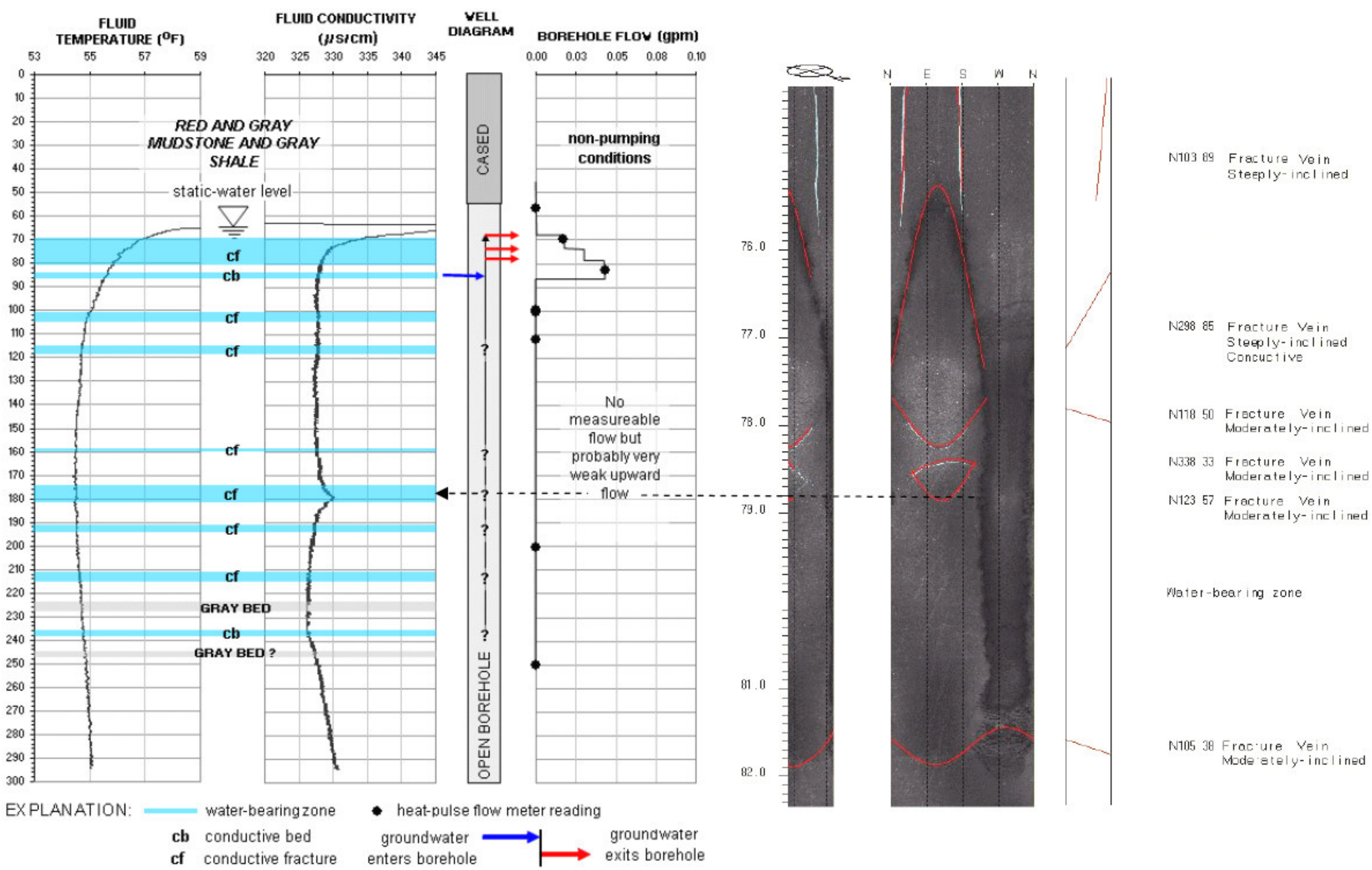


FIGURE 3O2. Hydrogeologic section (left) based on geophysical logs for well 105 in Pennington Boro, Mercer County, NJ, The section shows the vertical distribution and types of hydraulically-conductive features and water-bearing zones in red mudstone. OPTV record (right) shows geologic structures and hydraulically-conductive fracture. Depth values are in feet below land surface.

Table F4. Summary of projects, wells and WBFs, geophysical log collected and ranges of log values

PROJECT, AQUIFER, WELLS AND WBFs							GEOPHYSICAL LOGS COLLECTED													LOG-RESPONSE VALUES				
Appendix Entry	NJGS Project	Aquifer or aquifer zone(s)	no. of wells	no. of WBFs			Imaging			Fluid				HPFM		Formation				fluid resistivity	fluid conductivity	borehole flow (np)	formation natural gamma bswl	formation single-point resistance bswl
				L	F	LFI	O	A	B	FC	FR	FT	PA	np	pu	C	G	SP	SL	(ohm-m)	(μs/cm)	(gpm)	(cps)	(ohms)
1A	258 S. Franklin AGW	diabase	1	7	3	1	X		X	X	X	X		X	X		X	X		14-30	328-700	0.3	20-105	1595-2074
1B	Snydertown Rd AGW	diabase	4	4	17	2	X		X	X	X	X		X		X	X	X		12-56	185-900	0.9	4-55	370-2900
1C	Crusher Rd.WS	diabase	1	1	4		X			X		X									205-475			
1D	Block 38, Lot 16 WS	diabase	1		7		X		X	X	X	X				X	X	X		7-71	141-1410		5-86	2920-2994
1E	Essex County CC WS	BW basalt	3	15	4	3	X		X	X	X	X		X				X		18-40	257-545	5.6	7-61	70-1550
1E	Essex County CC WS	BMR	1	3	1	1	X		X	X	X	X		X				X		22-36	280-285	0.5	30-160	123-300
1F	1163 Delaware AGW	BW basalt	1		6	1	X		X	X	X	X		X		X	X	X		7-28	354-1385	ND	6-42	500-2270
1F	1163 Delaware AGW	BMR	1				X		X	X	X	X		X		X	X	X		28-29	349-354	ND	15-195	140-234
2A	Ridgewood Shell GW	BMR	9	4			X																	
2B	Sandos-Clariant GW	BSC	2	6	6		X																	
2C	Hoffman-LaRoche GW	BSC	3	3	6		X																	
2D	Hamilton Farms WS	BSS	3	8	7	14	X			X		X									120-234	0.3		
2E	Milford Boro WS	BLGSC	5	22	8	8	X		X	X	X	X		X		X	X	X		15-43	230-1370	ND	44-560	1240-4288
2F	Passaic Flood Tunnel GI	BW-MR-LR	9								X	X	X			X	X		X					
3A	Flemington Boro WS	BMR	1	12	3		X		X	X	X	X				X	X	X		1-10	345-15000		52-208	1514-1564
3B	Hillside Car Wash WS	BMR	1	2			X			X		X									1742-1820			
3C	Readington Twp GW	BMR	9	18	12	1	X		X	X	X	X		X		X	X	X		28-103	65-290	3.8		
3D	Delaware Twp AGW	BMR	5	6	7		X		X	X	X	X		X			X	X		22-38	200-211	2.5	40-220	150-1020
3E	Potterstown Rt 22 GW	BMR	6	10	10		X		X	X		X			X					2-28	300-576	ND	17-320	120-450
3F	Trump National GC WS	BMR	7	1	32		X																	

(continued on next page)

Aquifer abbreviations: BW - Brunswick Watchung zone, BSC - Brunswick conglomerate sandstone zone, BSS - Brunswick sandstone zone, BLGSC - Brunswick lower gray zone with sandstone and conglomerate, BMR - Brunswick middle red zone, BMG - Brunswick middle gray zone, BLR - Brunswick lower red zone, BLG - Brunswick lower gray zone

Water-bearing feature (WBF) abbreviations: L - straigraphic layering, F - fracture, LFI - layer-fracture intersection

Geophysical log abbreviations: O - optical televiewer, A - acoustic televiewer, B - borehole video camera, FC - fluid conductivity (microseimens/centimeter), farenheit) FR - fluid resistivity (ohm/meters), FT - fluid temperature (F), PA straddle-packer, HPFM - heat-pulse flow meter, np - nonpumping, pu - pumping, C - caliper, SP - singe-point resistivity, SL - short-long normal resistivity, gpm - gallons per minute, cps - counts per second

(continued from previous page)

Table F4. Summary of projects, wells and WBFs, geophysical log collected and ranges of log values

PROJECT, AQUIFER, WELLS AND WBFs							GEOPHYSICAL LOGS COLLECTED													LOG-RESPONSE VALUES				
Appendix Entry	NJGS Project	Aquifer or aquifer zone(s)	no. of wells	no. of WBFs			Imaging			Fluid				HPFM		Formation				fluid resistivity	fluid conductivity	borehole flow (np)	formation natural gamma bswl	formation single-point resistance bswl
				L	F	LFI	O	A	B	FC	FR	FT	PA	np	pu	C	G	SP	SL	(ohm-m)	(µs/cm)	(gpm)	(cps)	(ohms)
3G	Hopewell Boro AGW	BMR	5	21	15	4	X		X	X	X	X	X	X	X	X	X	X	X	15-44	79-325	0.5	80-200	125-340
3H	Larison's Corner GW	BMG	1	2	9	1	X			X	X	X	X			X	X		X	28-36	870-895		58-300	103-386
3I	Home Depot GW	BMG	3	6	8	2	X			X	X	X		X		X	X	X		1-31	325-12000	ND	55-240	250-675
3J	Branchburg Rt202 GW	BMG	6	8	24		X																	
3K	Heron Glen GC-QNS WS	BMG	4	5	7		X		X	X	X	X			X	X	X	X		29-44	230-336	8.0*	75-320	630-760
3L	Harbat Farms WS	BLR	1		5		X		X	X											220-228			
3M	Stony/Honey Brook WS	BLR	9	20	29	9	X	X		X	X	X	X	X						9-60	264-448		50-367	47-933
3N	Bristol Meyers-Squibb GW	BLG	5	4	33	9	X	X		X		X	X	X							230-950	ND		
3O	Pennington Boro WS	BLG	1	2	7		X			X		X		X							325-335	ND		
3P	The Ridge GC WS	BLG	2	3	8		X			X		X					X				250-850		15-4012	
3Q	Snydertown Rd GWS	BLG-L	2		4	2	X			X	X	X				X	X	X		18-38	263-538		30-2686	310-1685
4A	Terhune Orchards GWS	L	2	2	3	3	X			X		X				X	X	X			225-390		50-960	439-1717
4B	Hilltop Development WS	L	5	2	24	2	X			X		X		X		X	X	X			255-820	ND	50-1750	350-1400
4C	29 Pine Hill Rd. AGW	L-S	1	6	5	1	X			X	X	X	X	X			X	X		14-24	431-690	0.9	75-650	10-1250
4D	Ewingville Rd & Rt31 GW	S	3		1		X																	
4E	Green Acres CC WS	S	2	3	12	3	X			X	X	X		X	X	X	X	X		14-55	280-857	3.8	5-540	540-860
4F	Springdale GC WS	S	3	8	11	7	X			X	X	X		X		X	X	X	X	14-55	250-425	15.0	50-600	100-600
4G	Princeton Plasma Physics GW	S	3					X																
		Totals	129	200	337	73														1-103	2-15000	ND - 15.0	1-4012	10-4288

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Water-bearing features (WBFs): L - straigraphic layering, F - fracture, LFI - layer-fracture intersection

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* flow measured while two irrigation wells were pumping nearby

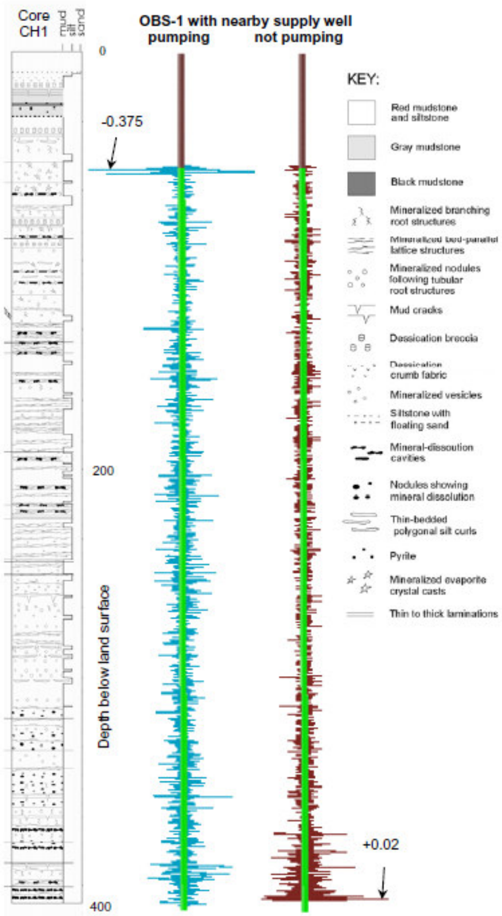
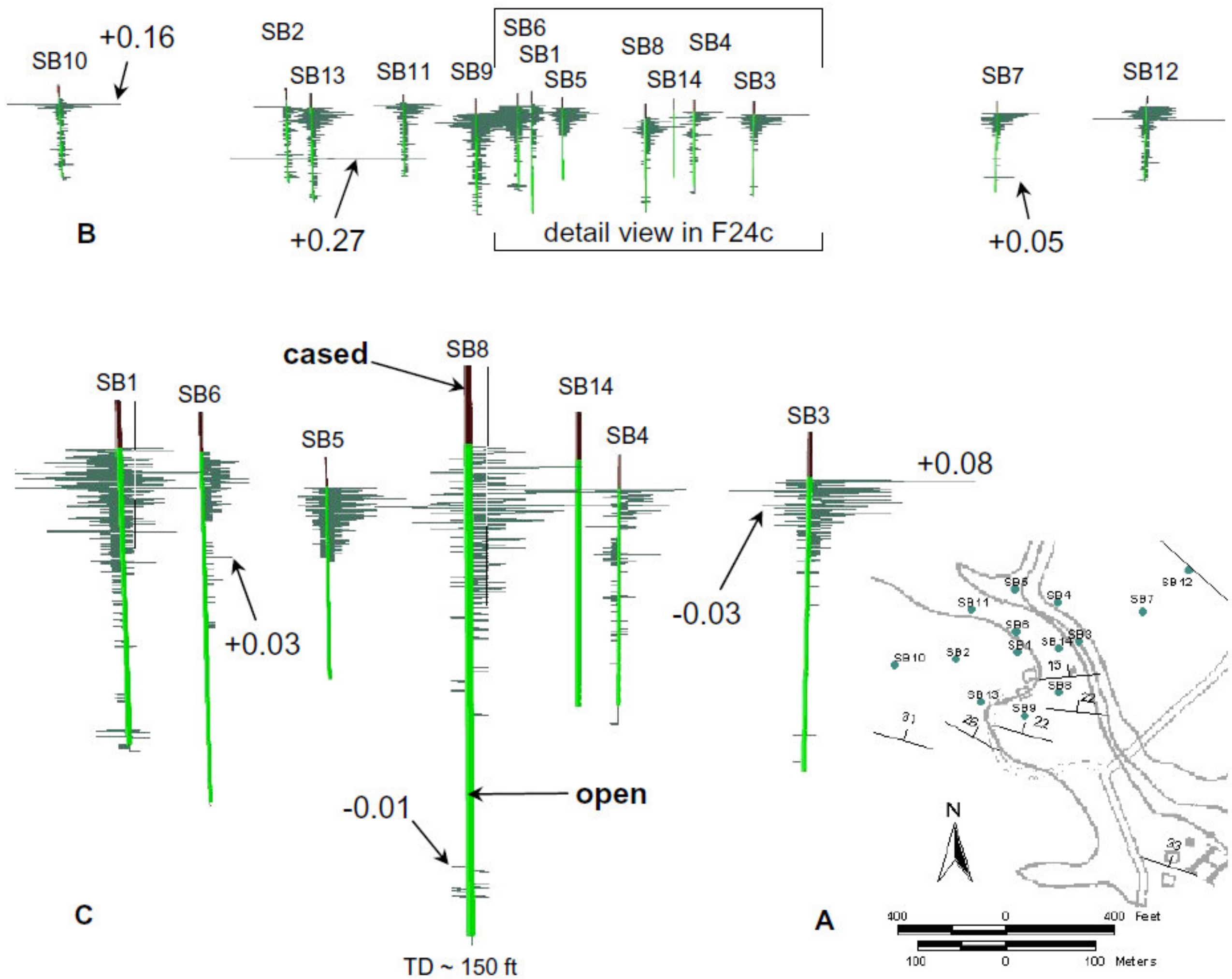


Figure F25. Diagrams comparing fluid-temperature differences (°F) in Hopewell Borough well OBS-1 (Well 69, Appendix 3G) for pumping (left) and non-pumping (right) conditions. Diagrams are plotted next to stratigraphic diagram of nearby core (left). Temperature differences under nonpumping conditions are an order of magnitude lower than those for pumping conditions. Note the correlation between temperature anomalies and dissolution zones in the core and the pronounced temperature differences directly below casing under pumping conditions.



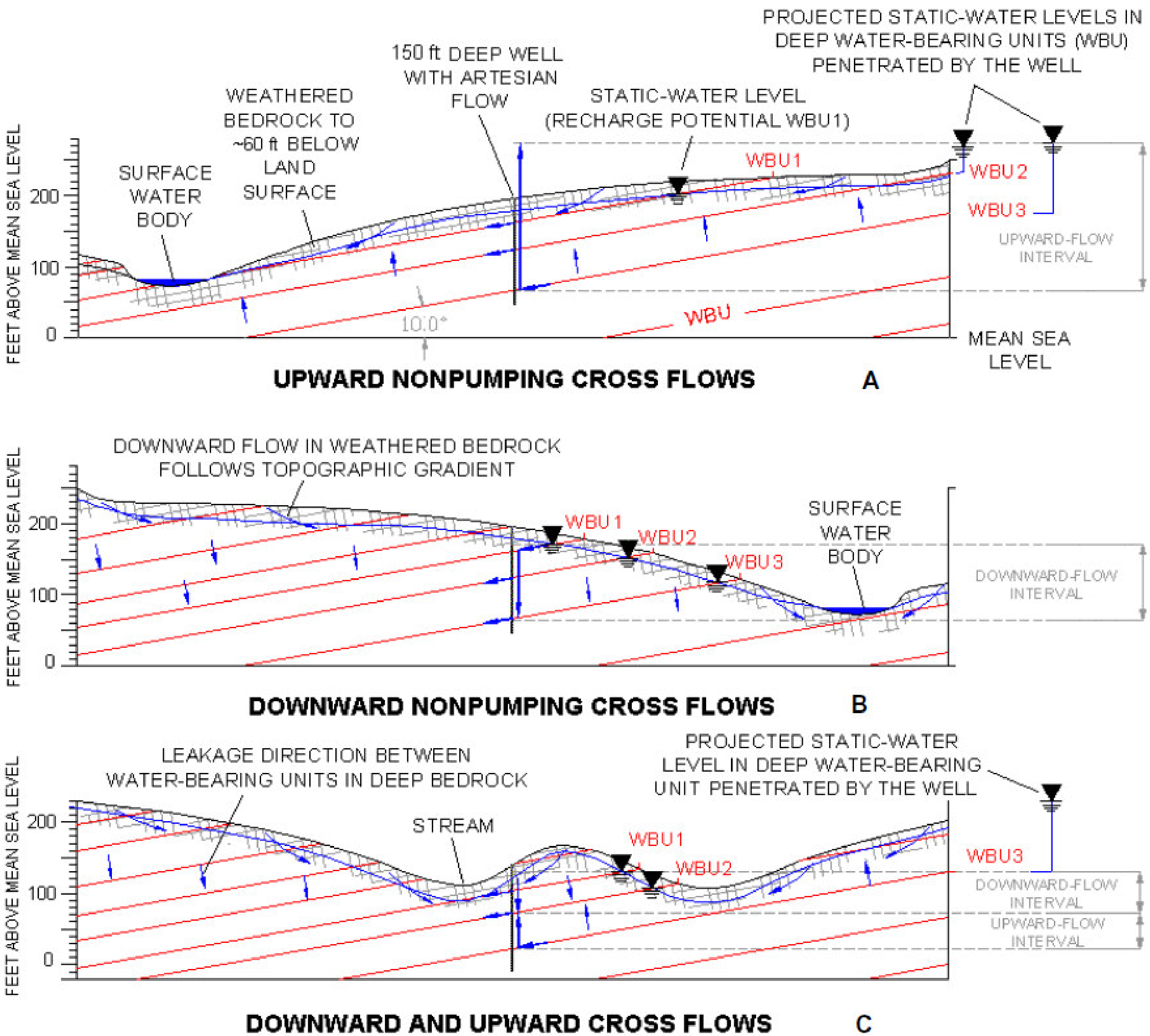


Figure F21. Profile diagrams illustrating the relationship between topographic grade and direction of cross flows in wells under natural (nonpumping) conditions.

Table F5. Types[1] of WBFs by aquifers, zones, units and groups of rocks

Aquifer	Zones, units and groups	No. of Wells	Type 1	Type 2	Type 3	Total	%1	%2	%3
Diabase…..	……………………………………………………	7	11	32	2	45	24	71	4
Brunswick…	……………………………………………………	93	181	247	54	482	38	51	11
Lockatong..	……………………………………………………	10	8	31	6	45	18	69	13
Stockton…..	……………………………………………………	12	13	25	10	48	27	52	21
TOTAL[2]…..	……………………………………………………	**119**	**213**	**335**	**72**	**620**	**34**	**54**	**12**
Brunswick	Basalt units in the Watchung zone (BWB)……..	4	15	10	4	29	52	34	14
Brunswick	Conglomerate and Sandstone (BC and BSC)…..	20	37	21	22	80	47	26	26
Brunswick	Sandstone (BSS)………………………………….	3	9	5	1	15	60	33	7
Brunswick	Middle Red zone (BMR)………………………….	33	70	79	5	154	45	51	3
Brunswick	Middle Gray zone (BMG)……………………….	14	21	48	3	72	29	67	4
Brunswick	Lower Red zone (BLR)……………………………	11	20	34	9	63	32	54	14
Brunswick	Lower Gray zone (BLG)…………………………...	10	9	50	10	69	13	72	14
Brunswick	Coarse-grained units (BC, BSC and BSS)………	23	46	26	23	95	48	27	24
Brunswick	Fine-grained units (BMR, BMG, BLR and BLG)..	68	120	211	27	358	33	59	8
Brunswick	Red Units (BC, BSC, BSS, BMR and BLR)……..	67	136	139	37	312	43	45	12
Brunswick	Gray Units (BMG and BLG)………………………	24	30	98	13	141	21	70	9
	Igneous rocks (diabase and basalt)……………..	11	26	42	6	74	35	57	8
	Sedimentary rocks…………………………………	110	187	295	67	549	34	54	12

[1]Type 1 – bedding planes and layers, type 2 – fracture planes, type 3 – linear intersections of bed and fracture planes

[2] Some wells penetrate more than one aquifer, group or unit so that the total number of wells and WBFs may not equal column totals.

Some conclusions from this research:

1) Borehole cross flows in well are systematic and commonly related to stratigraphic layering control on aquifer heterogeneity

2) WBFs and WBZs in gray beds are more concentrated in non-bedding fractures whereas those in red beds and especially coarser-grained units have more bed-parallel WBFs and Zs. The massive mudstone units have about an equal number, but the bed-parallel ones are higher transmissivities over longer distances.

3) Gray and Black shale units are confining beds to the red-bed aquifers.

4) The depth of weathering in bedrock is commonly 60 – 100 ft below land surface, so having more than 50-ft of casing for supply wells is advised

ALT & Mt. Sopris System 2011-

800 m 4MX2 Winch with
1/8” single conductor cable

Matrix data processor

Optical Borehole Image
(OBI-40) Tool

Heat-Pulse Flowmeter
HPFM-2293

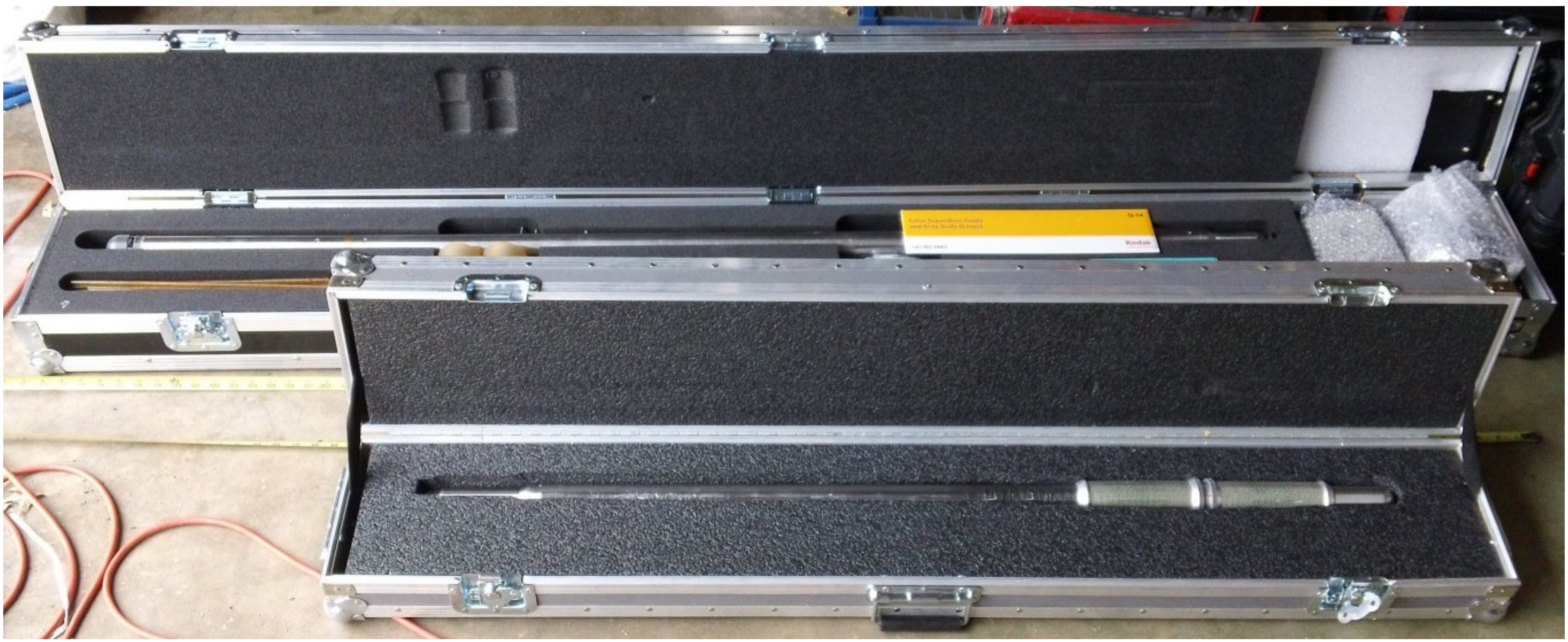
Advanced Logic Technology

www.mountsopris.com
MOUNT SOPRIS Instruments
Geophysical Logging Systems

NJGS acquired an Optical Borehole Imaging (OBI) System and HPFM in 2011 (Funded from the 1980 NJ Water-Bond)

ALT System

OBI	34,800
HPFM	10,800
800-meter winch 1/8” single-conductor	10,320
Equipment and software	9,900
Total ~	**$66,000**



OBI40 Optical Borehole Imager

2 Measurement Principle

The OBI incorporates a high resolution, high sensitivity CCD digital camera with matching Pentax optics. The CCD camera, located above a conical mirror, captures the reflection of the borehole wall. The light source is provided by a light ring assembly located in the optical head (Figure 2-1).

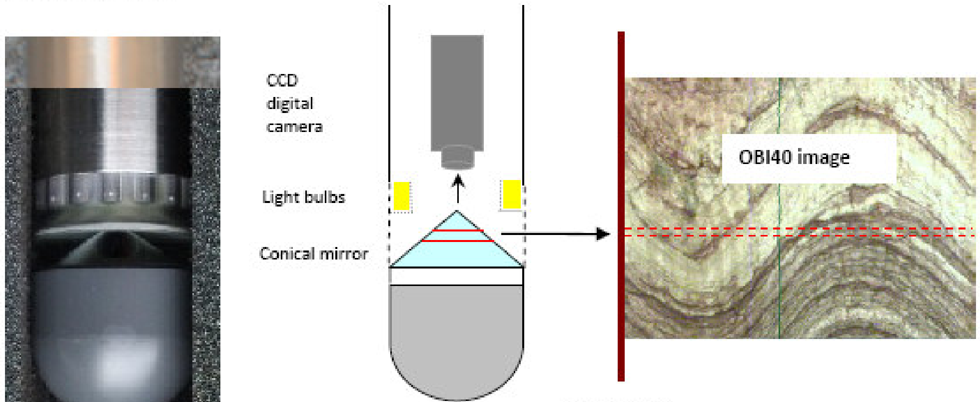
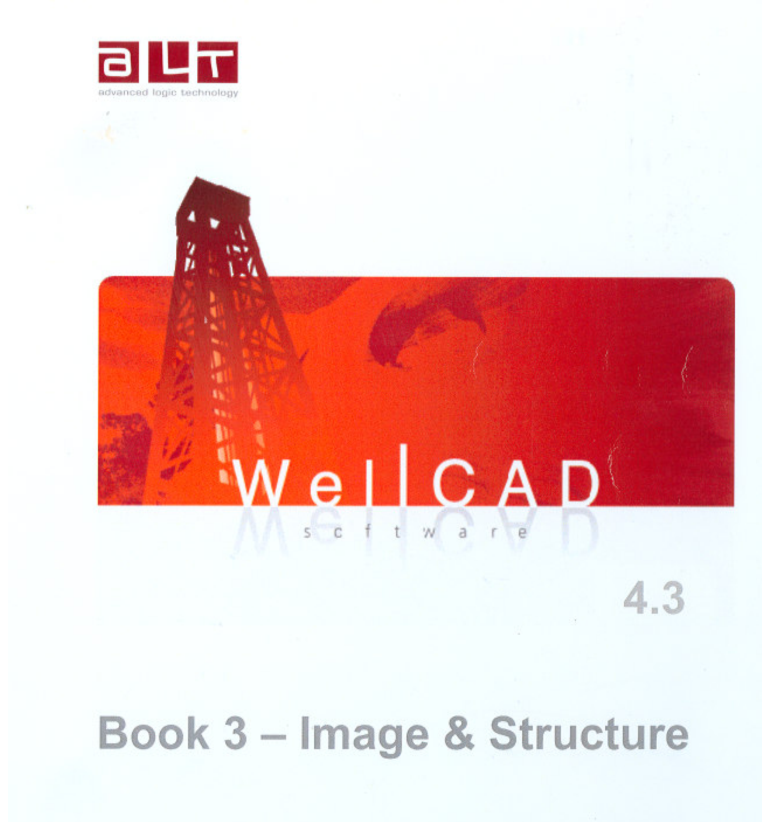
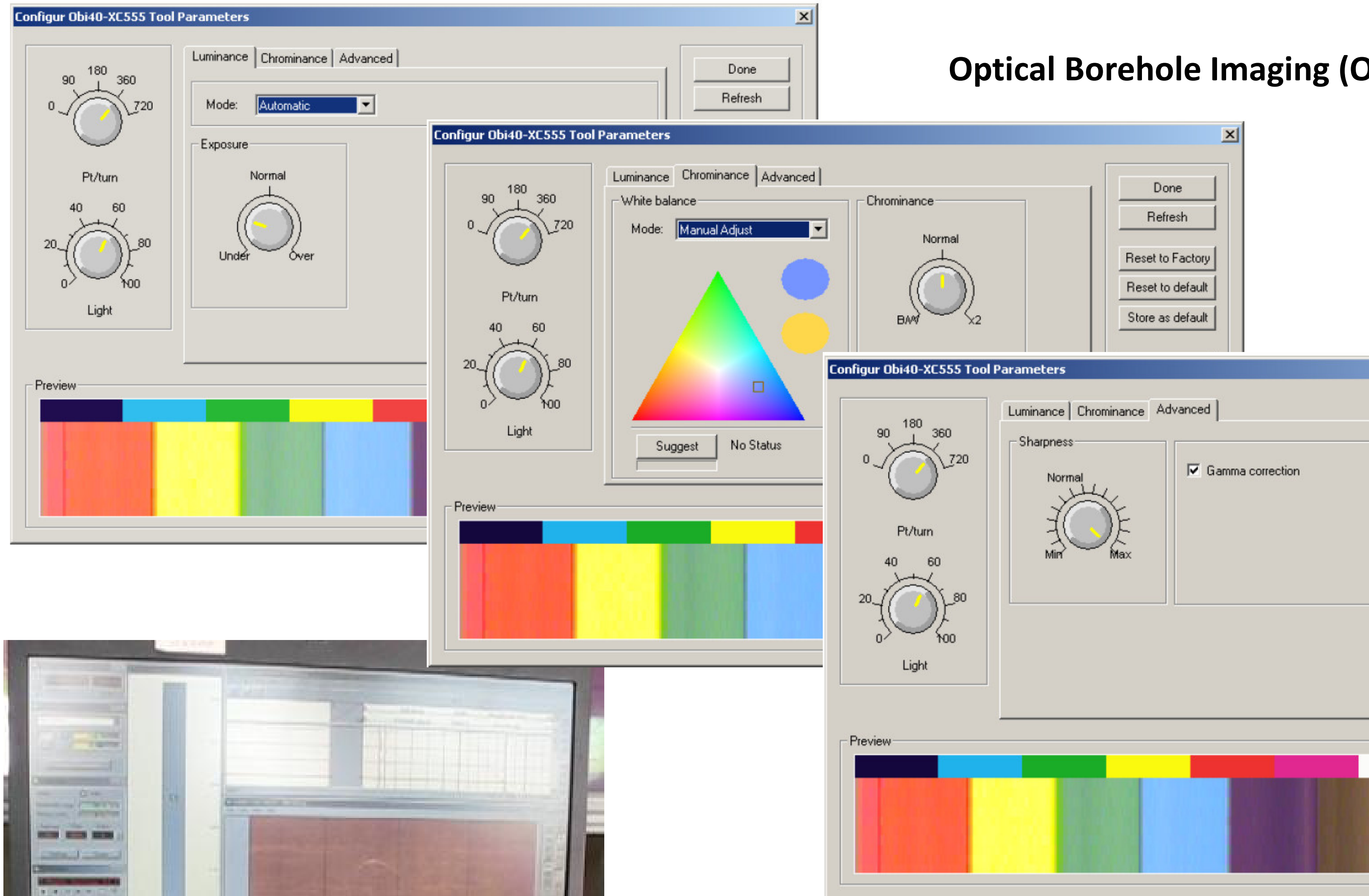
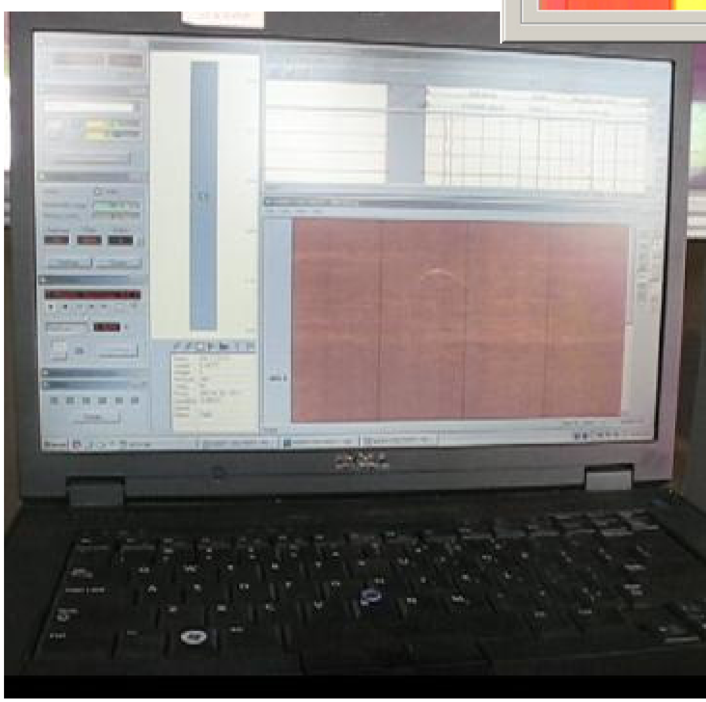


Figure 2-1 Optical assembly



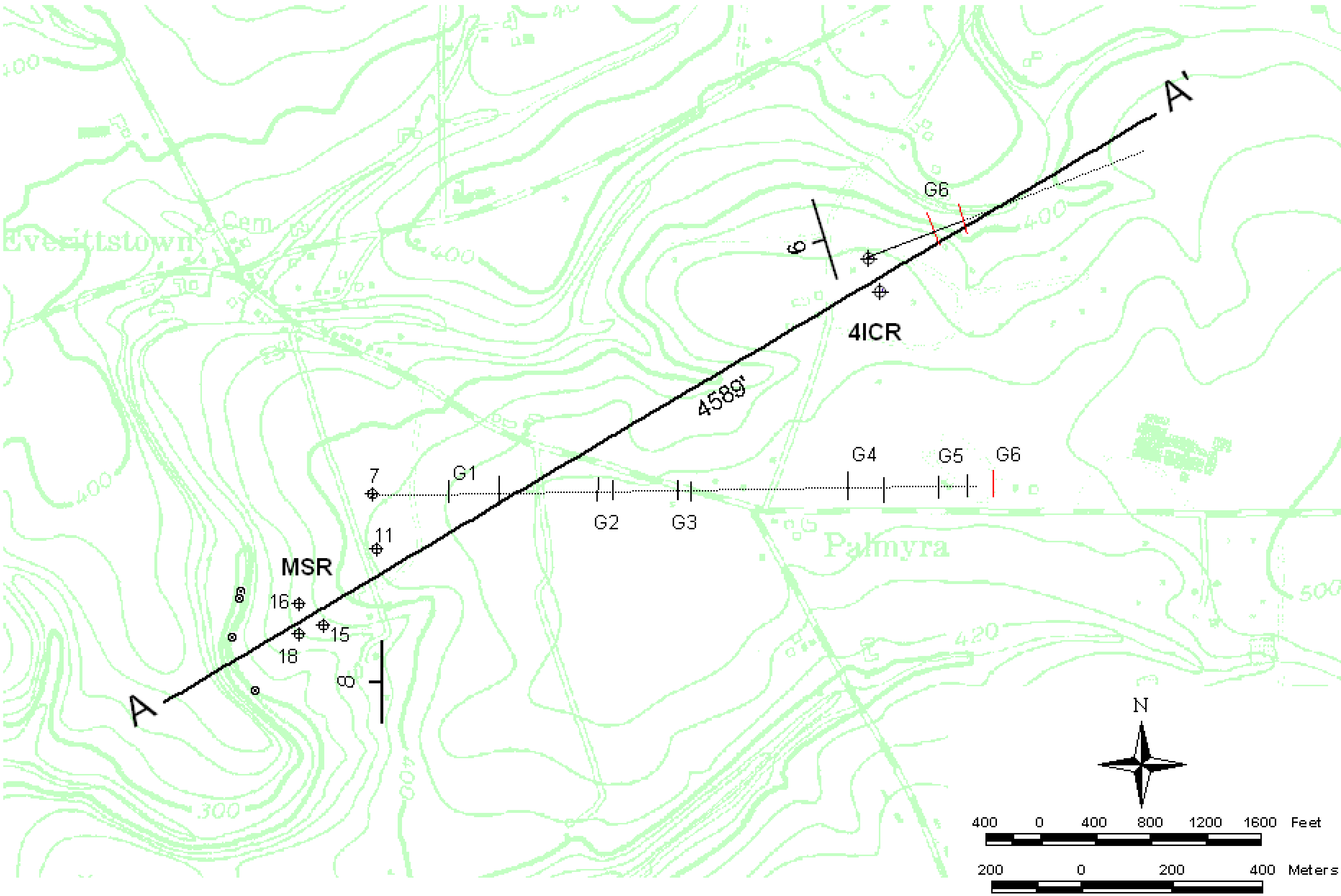
Optical Borehole Imaging (OBI) System





QL40 OBI and OBI40 User Guide.pdf

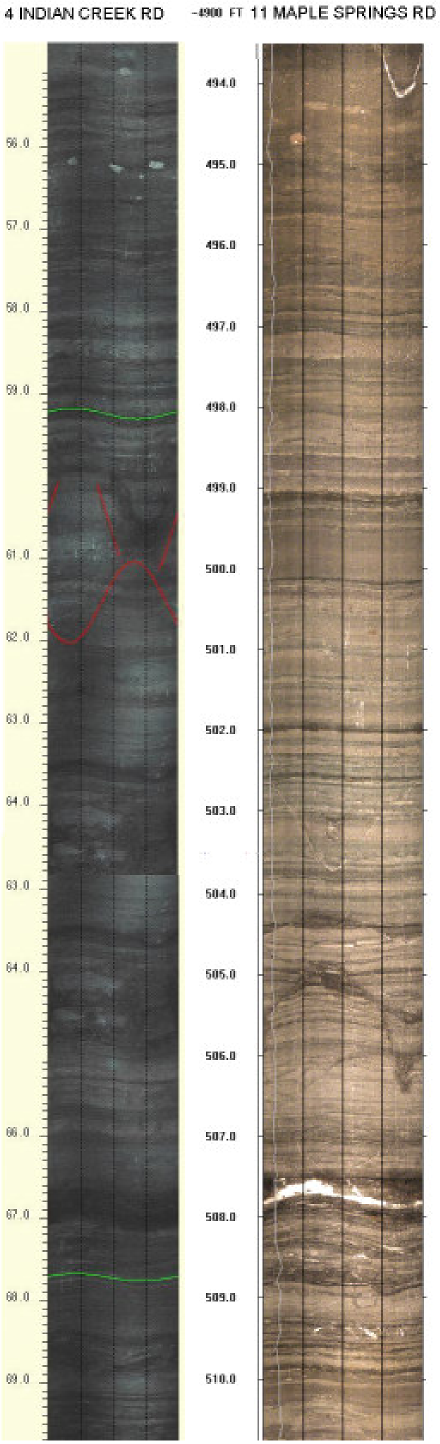
Figure 4-9 Color calibration jig



Base map from the US Geological Survey Frenchtown, NJ-Pa 7-1/2' Topographic quadrangle.

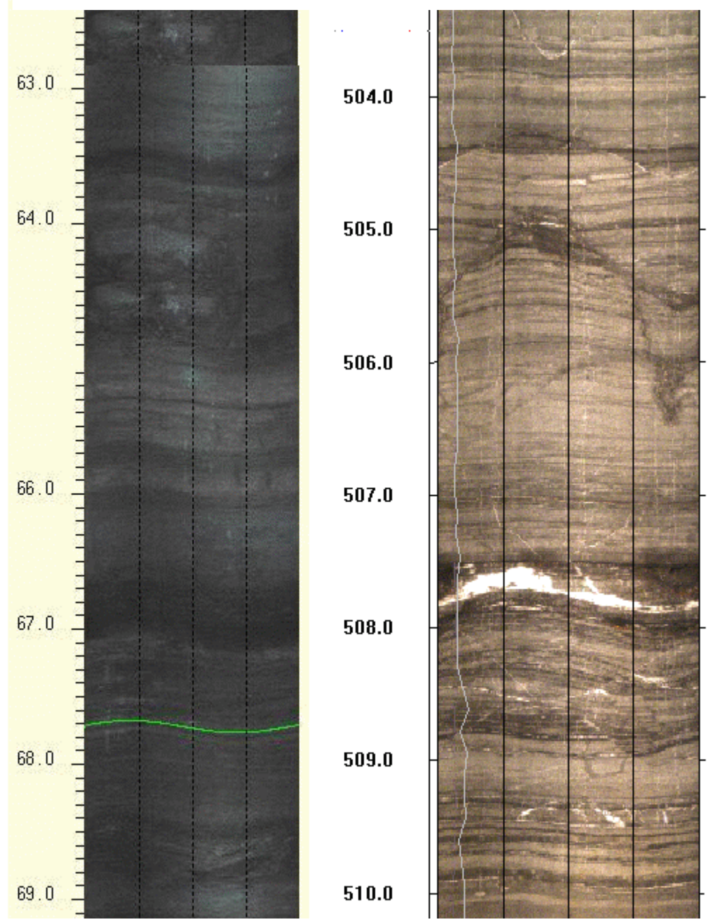
EXPLANATION:

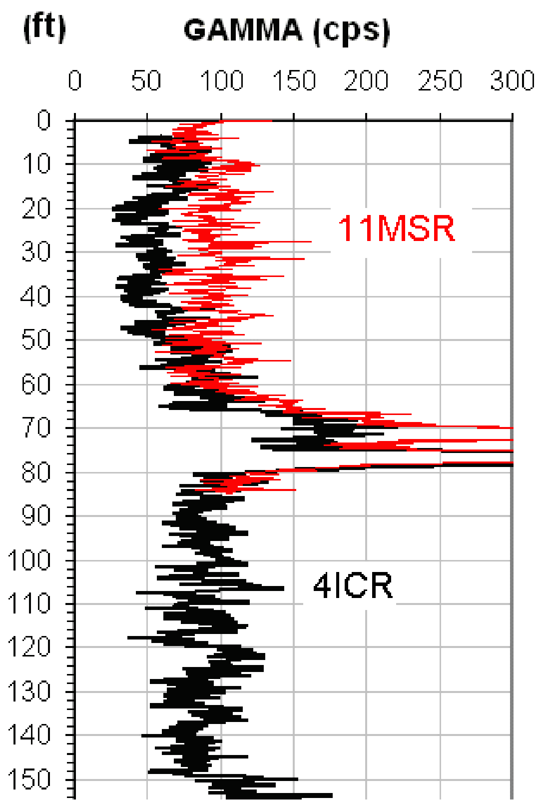
- Water well with line trace of penetrated stratigraphic interval
- A —— A' Cross-section trace
- Outcrop notes
- 8 Strike and dip from OBI image analysis



COMPARISON OF RG OPTV AND ALT-MT/SOPRIS OBI-40

Correlation of the "Borrelli bed" within the lower gray zone of the Brunswick aquifer, Warford (?) member of the Passaic Formation from Olsen and others (1996), using Gamma-ray and Optical Borehole Imaging logs.

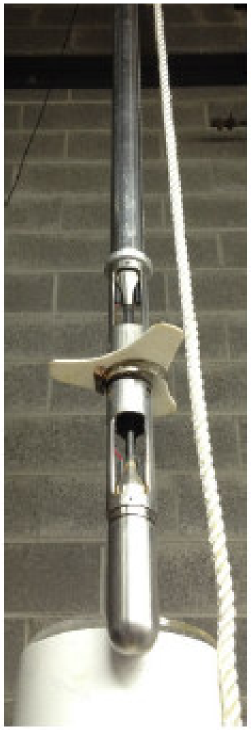


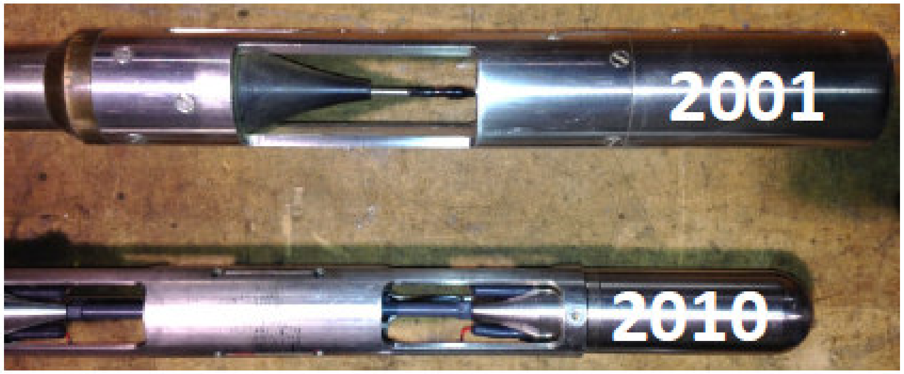


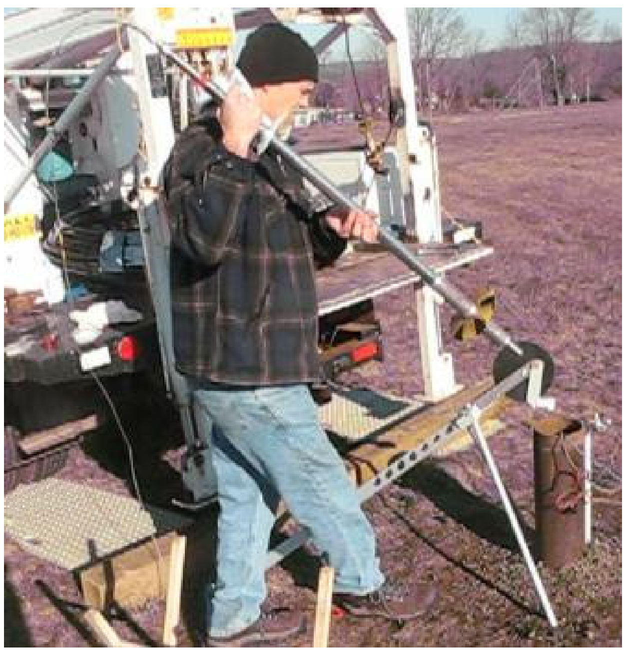
A heat-pulse (HPFM) is a geophysical sonde that is used to measure sub-vertical water-flow rates in wells.

A heat pulse is released into a moving water column, with the flow rate determined by the time it takes moving water to carry the heat pulse past heat sensors (thermistors) lying at fixed distances above and below the heat source.

HPFM technology was developed in the early 1980's and is in widespread use today for groundwater investigations involving open boreholes developed in fractured bedrock having discreet, permeable subsurface features (Hess, 1986; Hess and Paillet, 1990; Paillet, 1998).







The ALT- Mt.Sopris HPFM

Operational range with diverter/centralizer

Measuring Range

0.03 gpm to 1.0 gpm	0.113 lpm to 3.785 lpm
0.15 ft/min. to 13 ft/min.	0.046 m/min. to 3.962 m/min.

Resolution	**Accuracy**
5%	5% (Mid-Range) to 15% (Extremes)

Pressure Rating

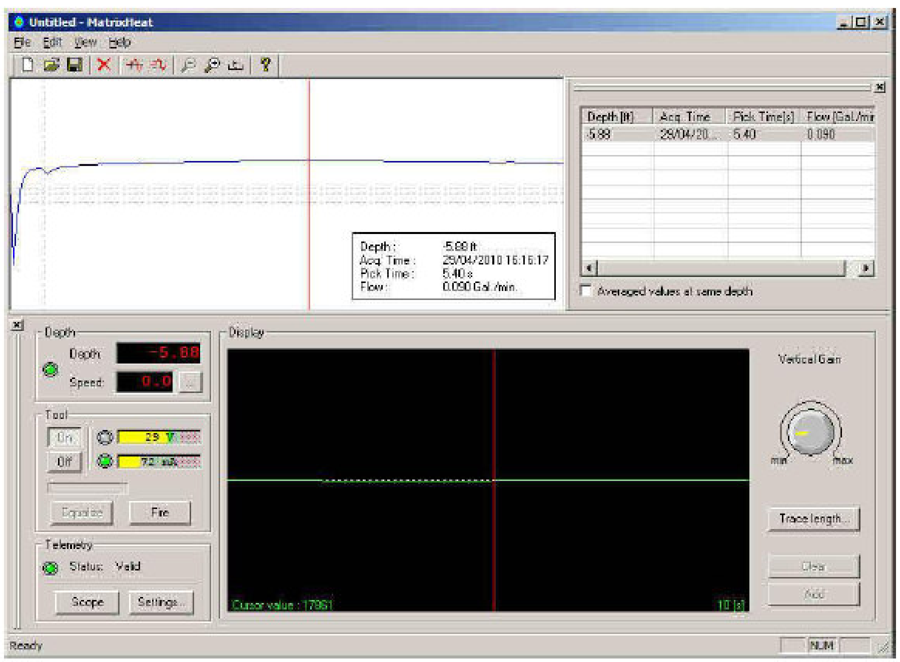
2000 PSI or 13789 Pascal (.43197 psi/ft = 878 ft)

The ALT-MT/SOPRIS and Robertson HPFM designs

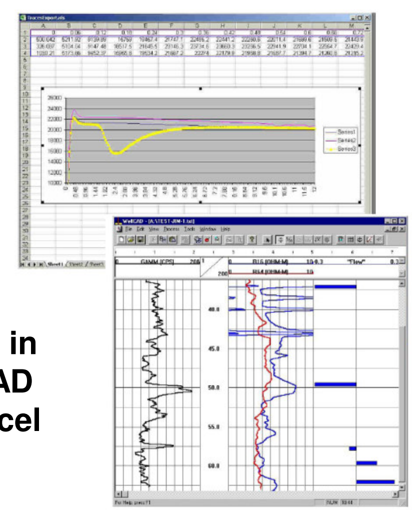
Interface detail

MatrixHeat Operator Manual

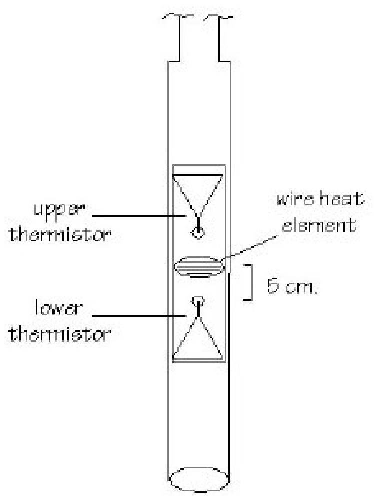
The ALT/MT SOPRIS Matrix Heat software interface

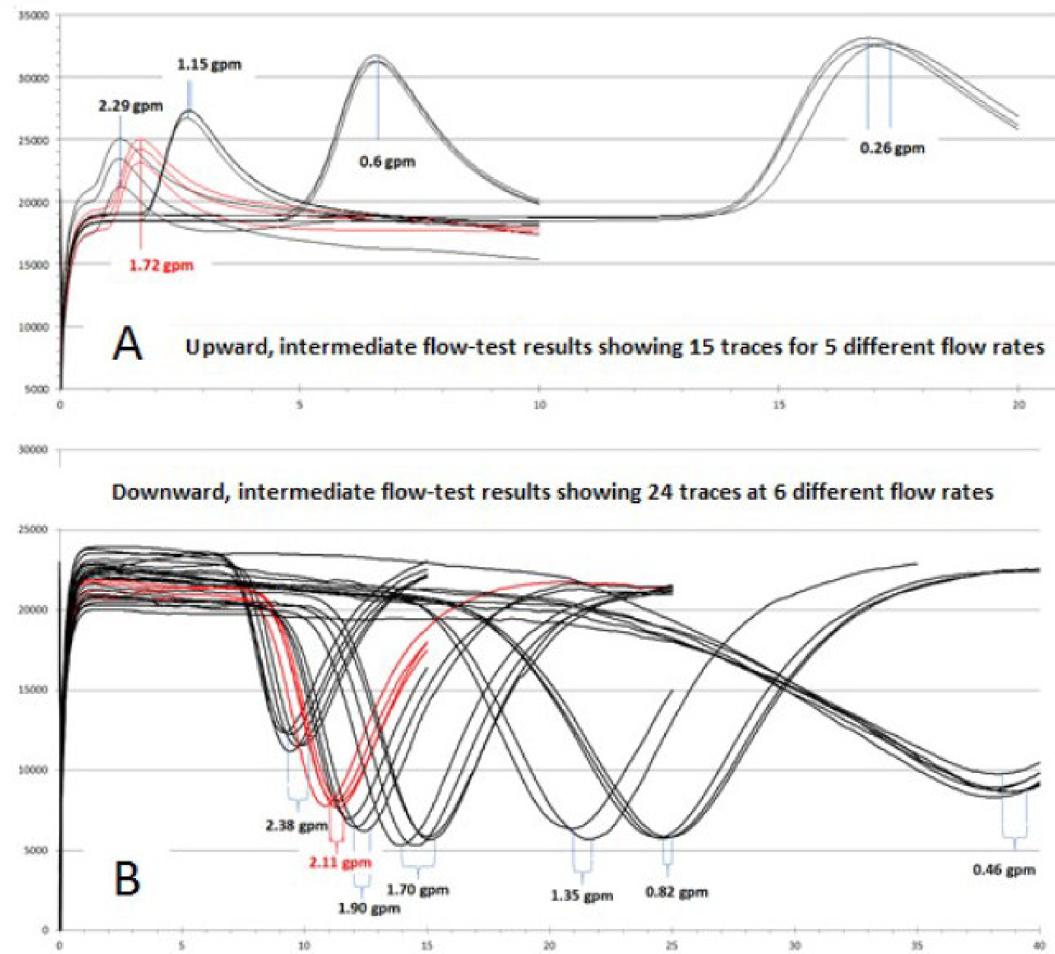


Output in WellCAD and Excel



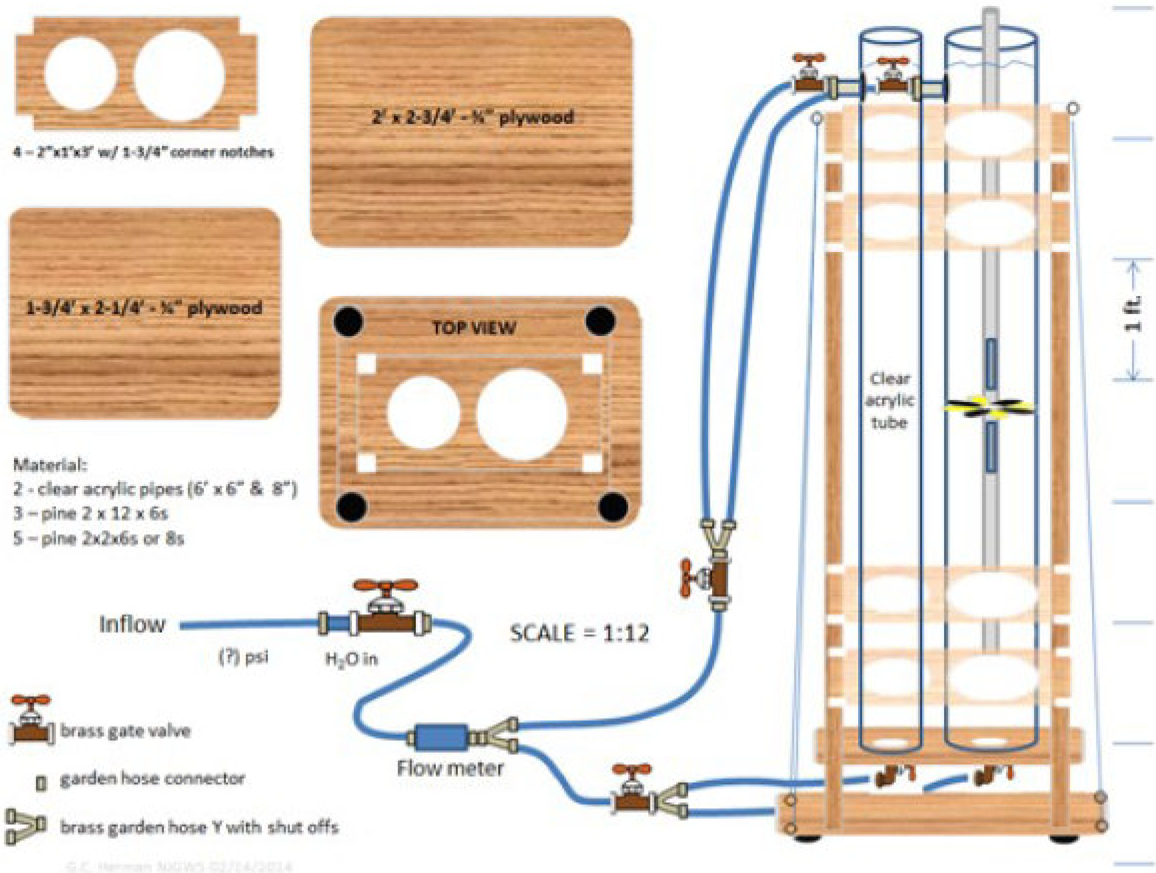
An instrument-response time (IRT) is the average time recorded for a given flow rate from multiple HPFM firing-and-response cycles triggered by an operator .





SketchUp CAD model

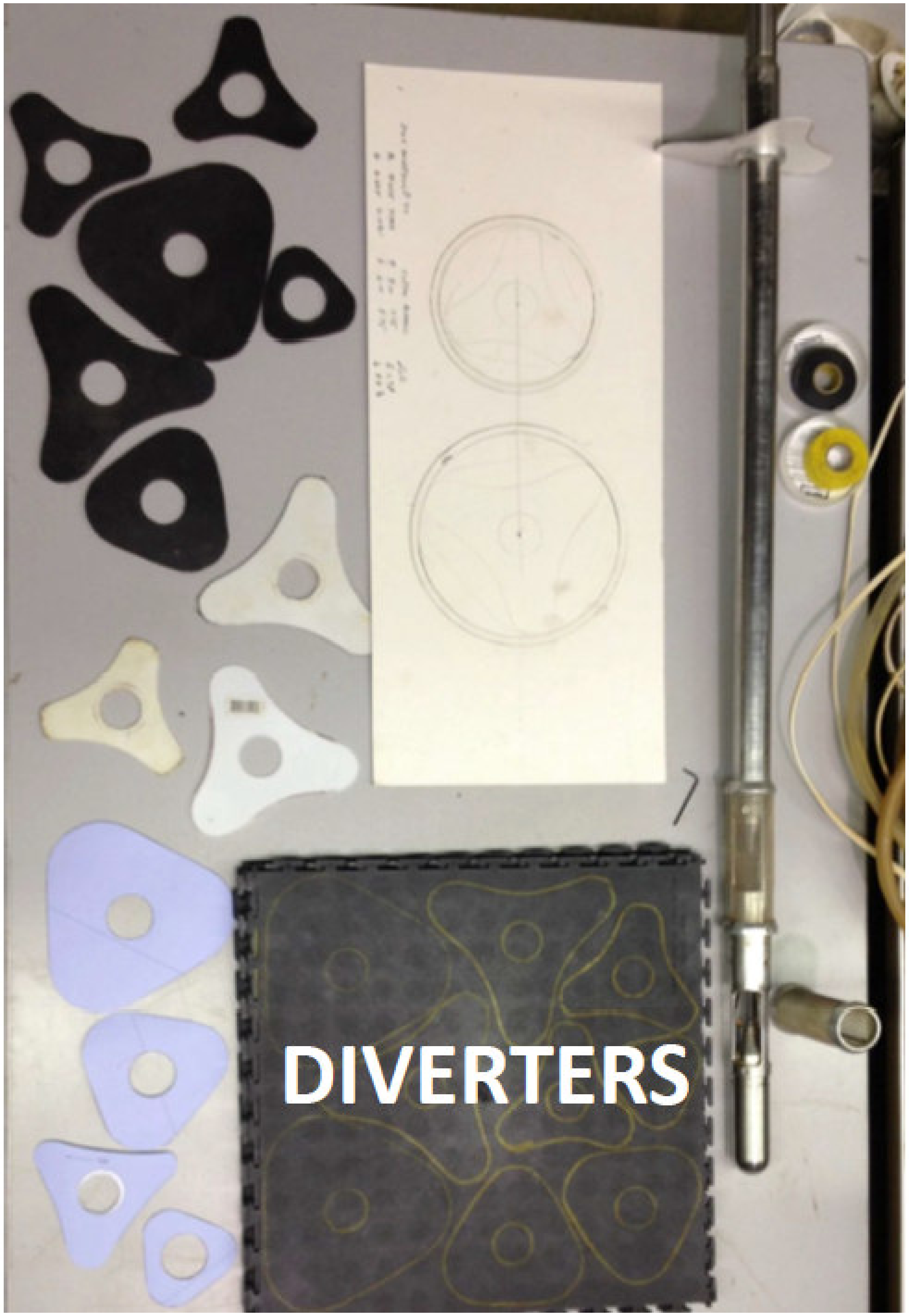
NJGWS Flow cha



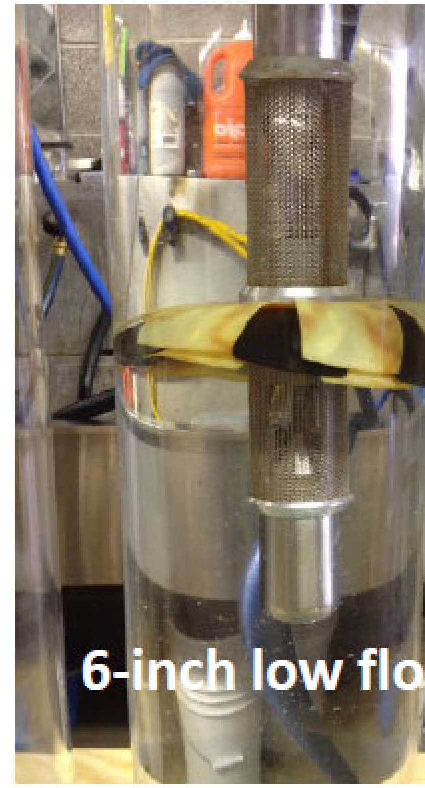
Volume of water in pipe (V) with water column (h)

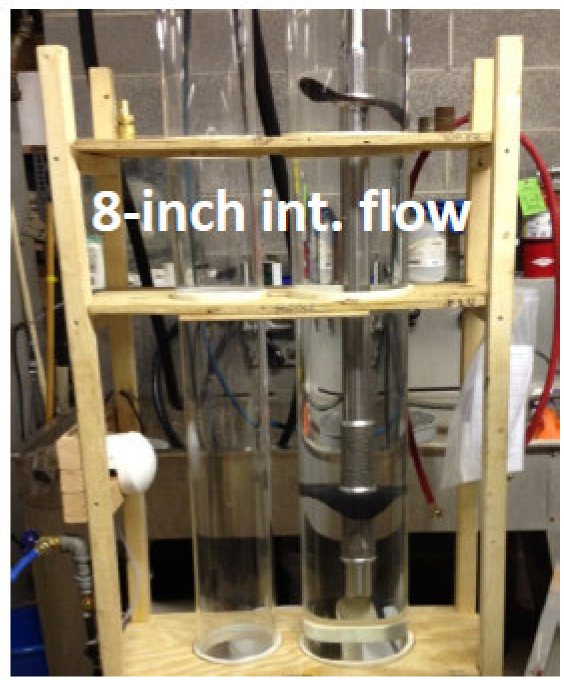
6" V = 1.47 h, 8" V = 2.81 h
6 in. volume = 1.47 gal/ft x 6 ft = 8.82 gal
8 in. volume = 2.81 gal/ft x 6 ft = 16.86 gal

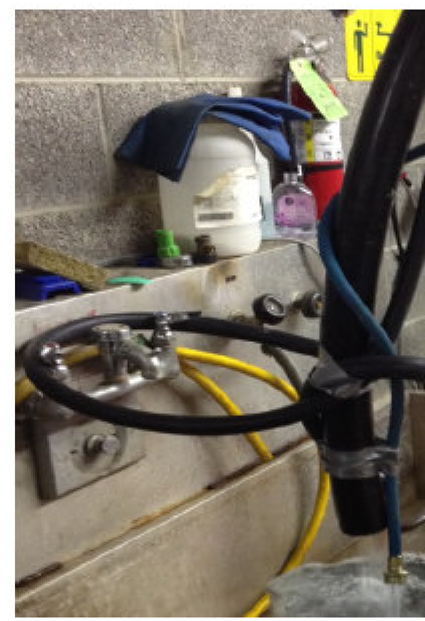
1 gallon of water = 8.342 pounds
6 in. weight = 73.57 psf at bottom (0.51 psi)
8 in. weight = 141.96 psf at bottom (0.985 psi)


DIVERTERS

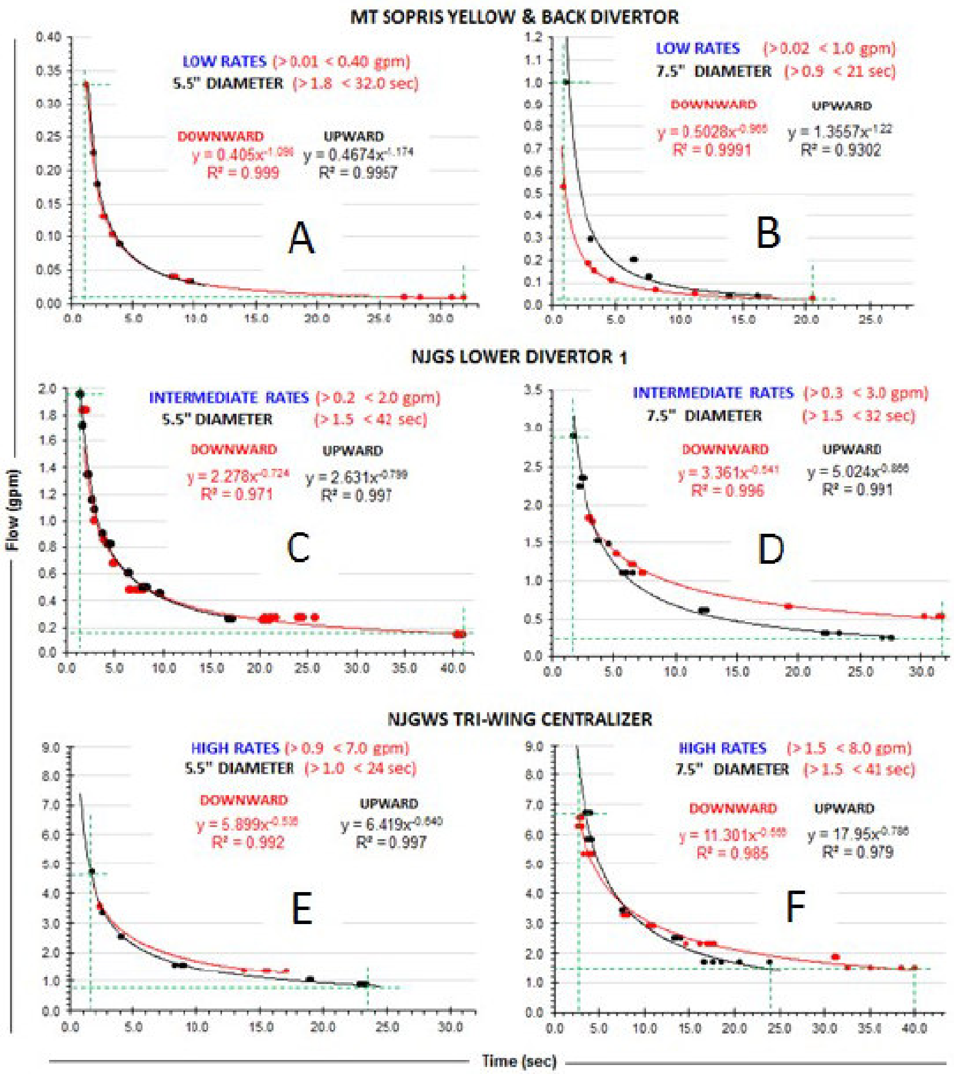

IN/OUT


6-inch low flo

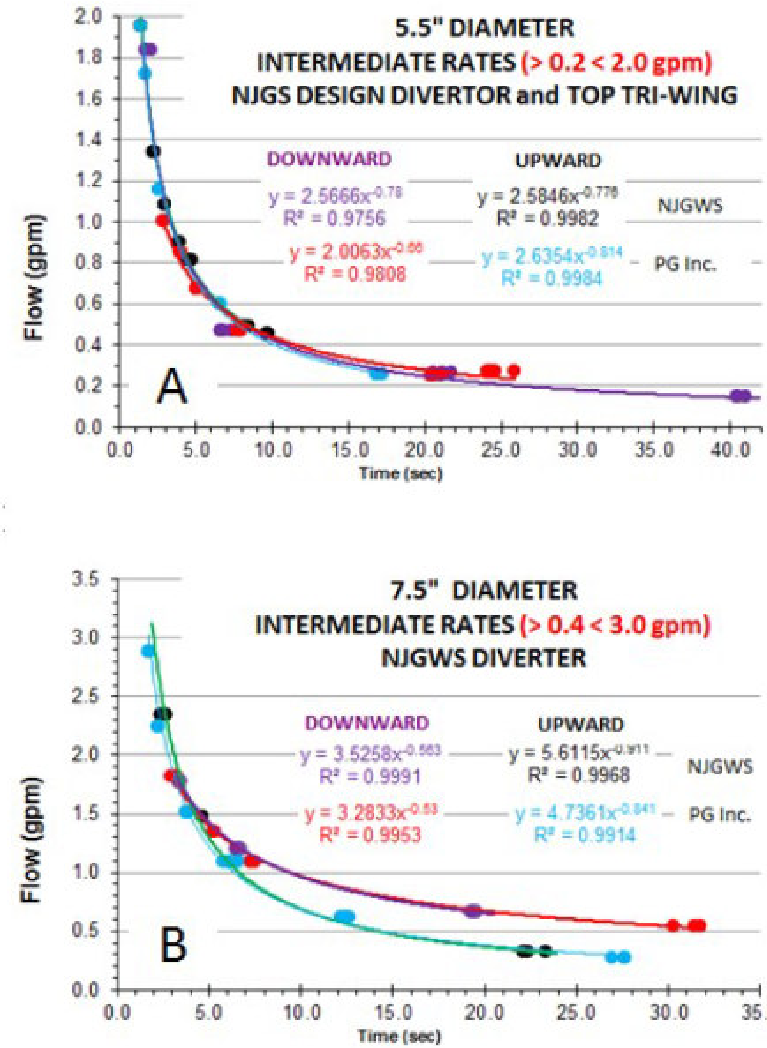

8-inch int. flow



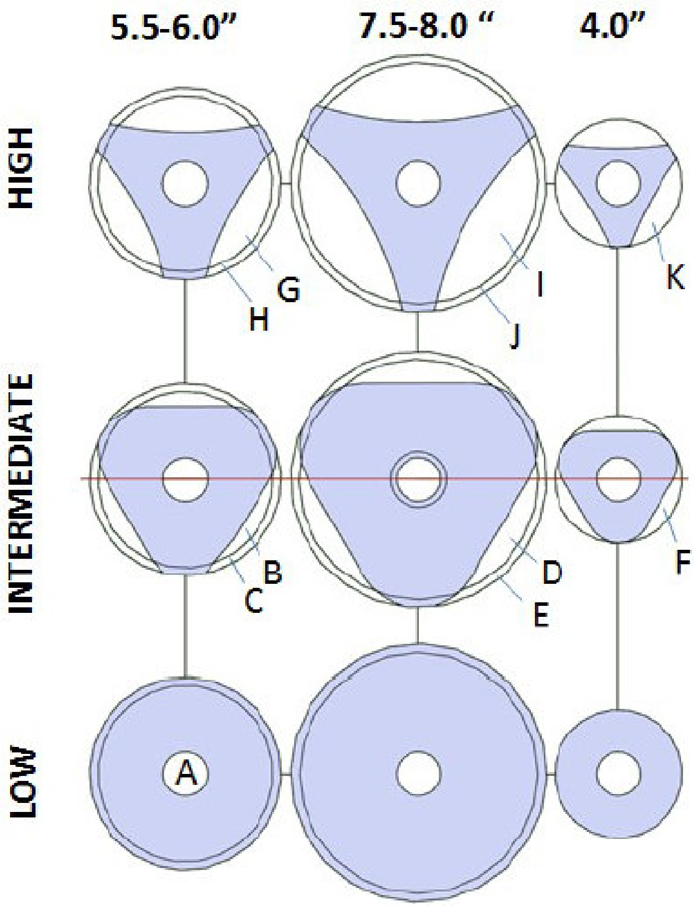
TWELVE TEST RESULTS / ONE PROBE



SIX TEST RESULTS / TWO PROBES

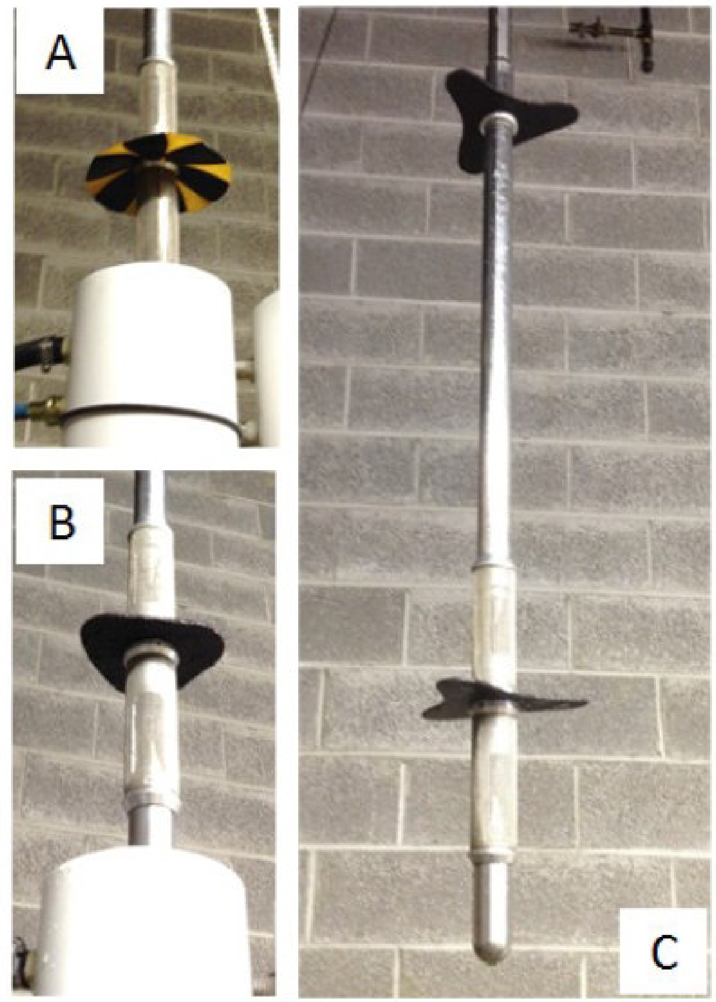


DIVERTER DESIGNS AND PASSING FLOW AREAS



Diverter segment	Area Inches²
A	1.31
B	3.31
C	3.21
D	6.91
E	4.63
F	5.53
G	9.06
H	3.65
I	21.91
J	5.20
K	5.53

THREE DEPLOYMENT SCHEMES COVERING 0.01 TO >10 GPM



HFR5.5	Calculated		
sec	down	up	% DIFF
2	4.068425	4.363137	-7.2
4	2.805913	2.730879	2.7
6	2.25782	2.076179	8.0
8	1.935184	1.709253	11.7
14	1.433685	1.17088	18.3
20	1.184203	0.920023	22.3
26	1.028851	0.770501	25.1
32	0.920488	0.669597	27.3
		AVG =	**14.3**

HFR7.5	Calculated		
sec	down	up	% DIFF
2	7.686776	10.4101	-35.4
4	5.228433	6.037335	-15.5
6	4.173158	4.389728	-5.2
8	3.556304	3.501352	1.5
14	2.605372	2.255318	13.4
20	2.136703	1.703942	20.3
26	1.84668	1.386422	24.9
32	1.645332	1.177651	28.4
		AVG =	**17.4**

IFR5.5	Calculated		
sec	down	up	% DIFF
2	1.379139	1.51216	-9.6
4	0.834953	0.86911	-4.1
6	0.622547	0.628605	-1.0
8	0.505495	0.499519	1.2
14	0.337099	0.319422	5.2
20	0.26038	0.240214	7.7
26	0.215334	0.194786	9.5
32	0.185279	0.165008	10.9
		AVG =	**6.2**

IFR7.5	Calculated		
sec	down	up	% DIFF
2	2.309996	2.756498	-19.3
4	1.587647	1.512397	4.7
6	1.274937	1.064561	16.5
8	1.091181	0.829801	24.0
14	0.806145	0.511096	36.6
20	0.664678	0.375282	43.5
26	0.576724	0.299008	48.2
32	0.515445	0.249798	51.5
		AVG =	**28.5**

LF5.5	Calculated		
sec	down	up	% DIFF
2	0.189201	0.20697	-9.4
4	0.088388	0.091727	-3.8
6	0.05663	0.056986	-0.6
8	0.041292	0.040653	1.5
14	0.022336	0.021075	5.6
20	0.015098	0.013865	8.2
26	0.011319	0.010189	10.0
32	0.009012	0.007985	11.4
		AVG =	**6.3**

LF7.5	Calculated		
sec	down	up	% DIFF
2	2.575736	2.756498	-7.0
4	1.319494	1.512397	-14.6
6	0.892235	1.064561	-19.3
8	0.675948	0.829801	-22.8
14	0.393896	0.511096	-29.8
20	0.279191	0.375282	-34.4
26	0.216743	0.299008	-38.0
32	0.177389	0.249798	-40.8
		AVG =	**25.8**

Comparative flow rates at different IRTs with summary of percentage differences between downward and upward axial flows (GPM) in the 2 to 32 second time window calculated using the derived power equations of table 1.

Table 5. Example results calculated using the MS Excel flow-calculator with some field-test results from 2011 (fig. 3) taken at high rates of flow when using the high-rate bypass diverter.

High rate of upward flow in a 5.5 to 6.2-inch diameter well								
CALIPER (in)	TIME (s)	$OFR_{6.0}$	$CFR_{5.5}$	ERR1%	$CAL_{5.5to6.2}$	AFR	**ERR2%**	PFA%
6	9.6	2.25	1.52	32.3	1.14	1.73	**12.1**	49.6
High rate of upward flow in a 7.5 to 8.2-inch diameter well								
CALIPER (in)	TIME (s)	$OFR_{8.0}$	$CFR_{7.5}$	ERR3%	$CAL_{7.5to8.2}$	AFR	**ERR4%**	PFA%
8	11	1.87	2.73	-45.8	1.07	2.54	**-35.7**	56.5

OFR-Observed flow rate (gpm), CFR-calculated flow rate (either for 5.5- or 7.7-inch hole in gpm), CAL-Caliper factor, PFA-Percentage passing flow area relative to borehole cross-section area

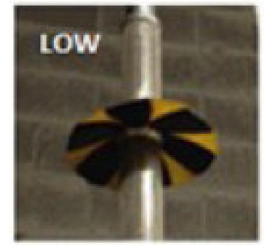
NJ GEOLOGICAL & WATER SURVEY FLOW CALCULATOR FOR A HPFM 2293

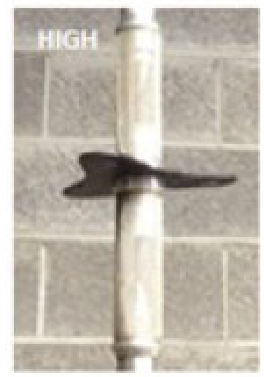
5.5 to 6.2-inch Diameter Boreholes

FLOW RATE & DIRECTION	FLOW RANGE GPM	TIME RANGE seconds	CALIPER inches	TIME seconds	FLOW GPM
LOW UP	> .01 < 0.4	> 1.8 < 32.0		5.3	0.066
LOW DOWN	> .01 < 0.4	> 1.8 < 32.0		20.0	0.015
INTER UP	> 0.2 < 2.0	> 1.5 < 42.0	6.0	20.0	0.34
INTER DOWN	> 0.2 < 2.0	> 1.5 < 42.0	6.0	20.0	0.37
HIGH UP	> 0.9 < 7.0	> 1.0 < 24.0	6.0	20.0	1.06
HIGH DOWN	> 0.9 < 7.0	> 1.0 < 24.0	6.0	20.0	1.35

7.5 to 8.2-inch Diameter Boreholes

FLOW RATE & DIRECTION	FLOW RANGE GPM	TIME RANGE seconds	CALIPER inches	TIME seconds	FLOW GPM
LOW UP	> .02 < 1.0	> 0.9 < 21.0		10.0	0.082
LOW DOWN	> .02 < 1.0	> 0.9 < 21.0		10.0	0.054
INTER UP	> 0.3 < 3.0	> 1.5 < 32.0	8.0	10.0	0.94
INTER DOWN	> 0.3 < 3.0	> 1.5 < 32.0	8.0	10.0	1.33
HIGH UP	> 1.5 < 8.0	> 1.5 < 41.0	8.0	10.0	2.74
HIGH DOWN	> 1.5 < 8.0	> 1.5 < 41.0	8.0	10.0	2.92





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Method for using a caliper function for refining calculated flow rates in variable-diameter boreholes when using the PFA diverter schemes