BRACKISH WATER EXPLORATION TEST WELL

CAPE HATTERAS WATER ASSOCIATION

FINAL REPORT

JUNE 2, 1995

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CAPE HATTERAS WATER ASSOCIATION

BRACKISH WATER EXPLORATION TEST WELL

FINAL REPORT

INTRODUCTION

This study was initiated by the Cape Hatteras Water Association as a first step in determining the viability of adopting Reverse Osmosis (RO) as the future water treatment technology for the Association. Boyle Engineering Corporation, with Missimer International, Inc. for hydrogeologic aspects, was retained as consultant for the work.

The scope consisted of constructing a small diameter test well, to a depth of approximately 600 feet, conducting low volume pump tests, and obtaining water quality data. The procedures and results are discussed in the Missimer International report found in Appendix A. Based on certain assumptions derived from the test well program, a conceptual process design for an RO water treatment plant was developed, and an opinion of cost derived from this design. It must be emphasized, however, that the approximate $1.15/kgal operating cost is valid only if the assumptions made in the conceptual design development remain valid. *If* the volume and quality of water from the limestone aquifer do not follow the patterns predicted in this report, the cost assumptions made will not be valid.

METHODOLOGY

Based on Missimer's input, a future water quality was created by adding sodium, calcium, chloride and sulphate to the water quality data derived from the test well. The change was made with 3200 ppm of sodium chloride, and 1000 ppm of calcium sulphate. Although it is likely that the magnesium fraction will increase magnesium is highly rejected, and its concentration contributes less to the average osmotic pressure than sodium It is also likely that the bicarbonate content will decrease, since any intrusion into the limestone aquifer will probably resemble seawater in its makeup. Since virtually all the bicarbonate is either converted to carbon dioxide in pretreatment, or rejected by the membrane, a reduction in this ion's concentration will not perceptibly alter the membrane performance results.

Based on the current average water demand, peaking factors, and potential for future expansion, it seems reasonable to assume an initial plant capacity of 1.6 MGD, with provision for two future trains of 0.8 MGD. The initial installation would consist of two RO trains, each with a permeate production of 0.8 MGD.

Having assumed deterioration of the brackish ground water resource's quality, the other considerations taken in this evaluation were for product water quality, and the possible limit of concentration for permitting the wastewater discharge. Given the performance of today's leading high rejection membranes, and the concentration factors involved in their use, there will be some small amount of blending capacity within this RO water treatment plant. There will initially be more, because of the lower feedwater TDS and chlorides at start-up. However, since the rate of increase of TDS cannot be accurately predicted at this point, we believe it prudent to base the plant capacity on the assumption that no blending will take place. Therefore, all product water will be permeate.

All of the four significant competing membrane products for this application exhibit sodium chloride rejection in excess of 99%. This means that the concentration factor (CF) calculated from the recovery is very nearly accurate, since the calculation assumes 100% salt rejection. Therefore, at 50% recovery, the CF is 2, 60% is 2.5, 70% is 3.33, and etc. By observation, it is readily apparent that at a recovery of 70%, the exiting concentrate will have a TDS approaching that of seawater (about 35,000 ppm). To attempt to operate the plant at a higher recovery could initiate a discharge permitting issue, particularly if the discharge is to Albemarle Sound, and not to the Atlantic. For this reason, in this study we have limited the recovery to 70%.

Utilizing projection software from one of the manufacturers, the third year pressure required for a 70% recovery using current state-of-the-art membrane is over 450 psig, based on a conservative flux design assumption. In the actual process design of such a plant, a lower feed pressure would probably result, especially initially. The use of an interstage boost pump between the first and second stage membrane assemblies should be considered. The net energy would be about the same, but the slight reduction in membrane area realized may be more than offset by the cost of a second pumping unit per train, and the associated piping, valves and controls. This situation would change if energy recovery is utilized, thereby reducing the overall energy requirement.

For this study, an initial recovery of 60% was assumed. For the future, membranes already on test are holding out the promise of significant energy savings. For Cape Hatteras, this boost in energy efficiency can be realized in increased recovery. This approach will save the groundwater resource, and reduce well pumping costs. Consequently, projections were made for future membrane at both "low" (60%) and "high" (70%) recoveries. Once again, the future constraint on recovery will probably be the wastewater concentration, and its possible effect on discharge permitting.

OPINION OF COST

Based on the preceding discussion, it is our opinion that the capital cost of the RO facility can be summarized as below. It is assumed that two wells with pumps rated at 475 gpm will be needed for each RO unit, for a total of 6 pumps. A spare well is included in the cost estimate.

		$M	
1.	Process equipment, installed	2.35	
2.	Process building for 4 RO units	0.75	
3.	7 wells, open hole construction	1.05	
4.	Raw water transmission	0.75	
5.	Finished water storage, 3 MG	0.75	
6.	High service pumping	0.35	
	Constructed Cost	6.00	
	Contingency @ 20%	1.20	
		7.20	
	Legal, admin, Eng, etc. @ 25%	1.80	
	Opinion of project cost	$9.00M	for 2.4 MGD

The following assumptions were made in developing this capital cost opinion.

1. Building cost at $100/sf
2. Raw water transmission piping based on 8" and 18" at $20/ft and $45/ft respectively.
   10,000 cf of 18"
   3,500 cf of 8"
   $25,000 per wellhead for enclosure, site work, etc.
   + Miscellaneous valve pits, etc.

Operating parameters are developed in the tables attached to this report. A significant cost is for post-treatment to stabilize the finished water. An approach similar to that used at Kill Devil Hills has been assumed. Acid is added to the feedwater to generate carbon dioxide, which is then converted to bicarbonate in the product water by the addition of caustic soda. Product water rehardening is proposed by the addition of calcium chloride. The cost of these two steps amounts to about $0.22/kgal of product. However, the finished water must comply with the Lead and Copper Rule of the Safe Drinking Water Act, and therefore must be stable. Detailed process design should include techniques to reduce this cost.

An operating cost, excluding labor and spare parts, of about $1.00/kgal of product in storage seems reasonable. This cost includes membrane replacement and a cleaning allowance. The Kill Devil Hills RO plant, in the most recent Annual Report, reported a maintenance and spare parts cost of less than $0.05/kgal. This cost should be comparable for a Cape Hatteras facility. A well operation and maintenance cost of $0.15/kgal of product appears reasonable

The cost of constructing an RO water treatment plant, as discussed above, does not include any extraordinary costs associated with disposal of the concentrate. It is assumed that an outfall from the plant, assumed to be located on the Foster tract (owned by the Association) to the Albemarle Sound is the preferred method of disposal and is believed to be permittable. An extension of this concept is to discharge the concentrate through the canal system at Brigands Bay. An advantage of this alternative is the dilution effect of the canal system prior to discharge into the open sound. As a further control on concentrate quality, some of the existing shallow wells could be maintained and utilized for dilution water as required. Any of these approaches to concentrate disposal are purely conjectural at this stage and will require further investigation and discussion with the various permitting agencies involved.

```
HYDRANAUTICS RO system design software -- v 5.5 (c) 1994             06-02-95
RO program licensed to:  Ian C.Watson, P.E.
Calculation created by:  Ian C. Watson

Project name:  CHWA. Future TDS, lo Y     Permeate flow:               800000.0 GPD
HP Pump flow:             925.9 GPM       Raw water flow:             1333333.3 GPD
Feedwater temperature:     20.0 C ( 68F)  Permeate recovery ratio:       60.0 %
Raw water pH:               7.60          Element age:                    3.0 years
Acid dosage, ppm (100%):   31.8 H2SO4     Flux decline coefficient:    -0.030
Acidified feed CO2:        40.2 PPM       3 yr salt passage increase:  1.3
Feed pressure:            382.7 PSI       Recommended pump pressure: 403.7 PSI
Average flux rate:         11.8 GFD       Feed water: Well water

Pass    Feed Flow       Conc. Flow      Beta   Conc.    Element       Elem.  Array
        Pass  Vessel    Pass  Vessel           Press.    Type          No.
        GPM    GPM      GPM    GPM             PSI

 1     925.9   44.1    455.1   21.7     1.10   362.5  8040-LSY-CPA2   126    21x6
 2     455.1   45.5    370.4   37.0     1.02   330.1  8040-LSY-CPA2    60    10x6

+----+----Raw water----+---Feed water----+----Permeate-----+---Concentrate---+
|Ion |  mg/l    CaCO3  |  mg/l    CaCO3  |  mg/l    CaCO3  |  mg/l    CaCO3  |
+----+-----------------+-----------------+-----------------+-----------------+
|Ca  |  384.0   957.6  |  384.0   957.6  |   1.8     4.5   |  957.3   2387.3 |
|Mg  |   81.9   337.0  |   81.9   337.0  |   0.4     1.6   |  204.2    840.2 |
|Na  | 3656.0  7947.8  | 3656.0  7947.8  |  82.1   178.4   | 9016.9  19602.0 |
|K   |   40.3    51.7  |   40.3    51.7  |   1.1     1.4   |   99.1    127.0 |
|NH4 |    0.0     0.0  |    0.0     0.0  |   0.0     0.0   |    0.0      0.0 |
|Ba  |    0.0     0.0  |    0.0     0.0  |   0.0     0.0   |    0.0      0.0 |
|Sr  |    0.0     0.0  |    0.0     0.0  |   0.0     0.0   |    0.0      0.0 |
|CO3 |    0.4     0.7  |    0.1     0.1  |   0.0     0.0   |    0.0      0.0 |
|HCO3|  256.0   209.8  |  217.0   177.9  |   0.0     0.0   |    0.5      0.9 |
|SO4 |  862.0   897.9  |  893.2   930.4  |   8.3     6.8   |  530.1    434.5 |
|Cl  | 5782.0  8155.1  | 5782.0  8155.1  | 123.4   174.0   |14269.9  20126.8 |
|F   |    0.8     2.1  |    0.8     2.1  |   0.0     0.1   |    1.9      5.1 |
|NO3 |    0.2     0.2  |    0.2     0.2  |   0.0     0.0   |    0.5      0.4 |
|SiO2|   17.2          |   17.2          |   0.2           |   42.7          |
+----+-----------------+-----------------+-----------------+-----------------+
|TDS |11080.8           11072.7            222.1             27349.0         |
|pH  |   7.60              7.00              5.58                 7.39         |
+----+-----------------------------------------------------------------------+

                                      Raw water      Feed water     Concentrate
CaSO4 / Ksp * 100:                      15.9%          16.5%           51.3%
SrSO4 / Ksp * 100:                       0.0%           0.0%            0.0%
BaSO4 / Ksp * 100:                       0.0%           0.0%            0.0%
SiO2 saturation:                        13.2%          13.2%           32.9%
Langelier Saturation Index:              0.80           0.13            1.27
Stiff & Davis Saturation Index:          0.33          -0.34            0.44
Ionic strength:                          0.21           0.21            0.53
Osmotic pressure:                      116.0 PSI      115.9 PSI       290.9 PSI

These calculations are based on nominal element performance when operated
on a feed water of acceptable quality. No guarantee of system performance
is expressed or implied unless provided in writing by Hydranautics.

      Hydranautics (USA) Ph: (619) 536-2500  Fax: (619) 536-2578
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Preliminary RO System Evaluation

Cape Hatteras Water Association

Limestone Formation Water Quality Assumptions

Operating Parameter	Unit of measure	Current Membrane Technology	Developing Membrane Technology, Low Recovery	Developing Membrane Technology, High Recovery
Feedwater flow, one RO unit	gpd	1,333,333	1,333,333	1,142,857
Permeate flow	gpd	800,000	800,000	800,000
Recovery	%	60	60	70
Permeate quality	ppm TDS	206	275	261
Est. product quality	ppm TDS	337	406	329
Number of Membranes	ea	175	150	126
Prod'n per membrane	gpd/element	4571	5333	6349
Membrane Feed pressure	psig	382	302	349
Permeate backpressure	psig	12	12	12
Pressure allowance, fouling	psig	20	20	20
Feed pump suction pressure	psig	20	20	20
Misc. piping losses	psig	5	5	5
Feed pump boost pressure	psig	399	319	366

Preliminary RO System Evaluation

Cape Hatteras Water Association

Limestone Formation Water Quality Assumptions

Operating Parameter	Unit of measure	Current Membrane Technology	Developing Membrane Technology, Low Recovery	Developing Membrane Technology, High Recovery
Feedpump efficiency	%	82	82	82
Feedpump shaft power	hp	263	210	207
Motor & VFD efficiency	%	90	90	90
Unit power	kwhr/kgal of permeate	7	5	5
Balance of plant	kwhr/kgal of permeate	1	1	1
Bldg and Domestic	kwhr/kgal of permeate	1	1	1
Plant power	kwhr/kgal of permeate	9	7	7
Acid(100%)	ppm	32	32	32
Acid(93%)	ppm	34	34	34
	#/kgal of permeate	0.48	0.48	0.41
Scale Inhibitor	ppm	5.00	5.00	5.00
	#/kgal of permeate	0.07	0.07	0.06
Caustic Soda, 50%	#/kgal of permeate	0.62	0.62	0.62
Ca Chloride, 25%	#/kgal of permeate	1.80	1.80	1.80
Chlorine, @ 3ppm	#/kgal of permeate	0.03	0.03	0.03

Preliminary RO System Evaluation

Cape Hatteras Water Association

Limestone Formation Water Quality Assumptions

Cost Component	Unit Cost	Units	Current Technology	Future, Low Recovery	Future, High Recovery
Power, $/kw-hr	0.07	$/kgal of product	0.598	0.506	0.500
Acid, $/#	0.10	$/kgal of product	0.048	0.048	0.041
Scale Inh., $/#	1.25	$/kgal of product	0.087	0.087	0.074
Caustic, $/#	0.22	$/kgal of product	0.136	0.136	0.136
Ca Chloride, $/#	0.05	$/kgal of product	0.090	0.090	0.090
Chlorine, $/#	0.20	$/kgal of product	0.005	0.005	0.005
Membrane, $/kgal	0.10	$/kgal of product	0.100	0.100	0.100
Cartridges, $/kgal	0.02	$/kgal of product	0.020	0.020	0.020
Cleaning, $/kgal	0.02	$/kgal of product	0.020	0.020	0.020
Opinion of Operating Cost			1.104	1.012	0.986

MISSIMER INTERNATIONAL INC.

RECEIVED
MAY 18 1995
BOYLE ENGINEERING
SANTA ROSA

May 15, 1995

Mr. Ian Watson, P.E.
Boyle Engineering Corporation
131 Stony Circle, Suite 750
Santa Rosa, CA 95401-9522

Re: Cape Hatteras Water Association - Reverse Osmosis
Feedwater Investigation

Dear Ian:

The construction and testing of the Cape Hatteras Water Association (CHWA) reverse osmosis test well TW-1 has been completed. A zone with the potential for producing large volumes of raw water has been identified based on results of the drilling and testing program conducted. The limestone unit which was encountered between the depths of 240 and 275 feet below land surface at the test drilling site is considered the most likely source of reverse osmosis feedwater on the island. The methods utilized during the preliminary investigation and results obtained are detailed on the following pages with conclusions and pertinent recommendations.

We appreciate having the opportunity to assist on this project and look forward to working with you again as development of the resource progresses. Please give me a call if you have any questions or comments.

Sincerely,

Wm. Scott Manahan
Water Resource Engineer

W. Kirk Martin, P.G.
North Carolina Professional Geologist
P.G. No. 1112

WSM/WKM/lk
Enclosure

FH4-088.RPT

8140 College Parkway, Suite 202
Fort Myers, Florida 33919
(813) 432-9494
FAX (813) 432-9453

CONSTRUCTION AND TESTING OF THE CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1

Conclusions and Recommendations

A test drilling program was completed near the Cape Hatteras Water Association water treatment plant on Hatteras Island. A highly productive limestone unit encountered between the depths of 240 and 275 feet below land surface at the test drilling site is considered the most likely source of raw water supply development for reverse osmosis treatment on the island. The productive capacity of the zone is very high and the water is of acceptable quality for treatment with brackish water reverse osmosis membranes. This source appears to be adequate to supply 3 MGD or more of raw water if the resource is properly managed. A considerable amount of additional testing and analysis will be required to fully evaluate the yield characteristics and water quality of the target aquifer. It is not possible to determine the long-term water quality stability of the source without obtaining additional information.

A drilling and testing program is recommended to obtain the necessary data. A test/production well and at least two observation wells tapping the producing zone should be constructed for aquifer performance testing purposes in the area proposed for wellfield development. Data collected during aquifer performance testing will be used to calculate aquifer hydraulic parameters including transmissivity, storage coefficient, and leakance. In addition, monitor wells should be constructed that tap discreet intervals near the top and bottom of the producing zone as well as zones above and below the low permeability units that provide confinement for the aquifer. These wells will provide information on the vertical variation of water quality in the sediments underlying the proposed wellfield area. Monitor wells tapping the production zone should also be constructed near the terminuses of the proposed wellfield alignment to assess lateral water quality variations. Data collected during the test program should be used to develop hydraulic and solute transport computer models of the aquifer system. The models can be used to determine a wellfield design and operation schedule that will result in a stable and reliable source of feedwater for the proposed reverse osmosis plant. Once developed, the models can also be used to evaluate the feasibility of various future wellfield expansion scenarios.

The monitor and observation wells constructed during the test program can be converted to permanent monitor well status for use when the proposed wellfield is in operation. Data obtained from the wells can be used to evaluate wellfield performance and for calibration of the hydraulic and solute transport computer models. The monitoring data will also provide an early warning of potential problems or unexpected water quality changes in the wellfield.

Introduction

Missimer International, Inc. (MI) was subcontracted by Boyle Engineering in March of 1995 to conduct test drilling for the Cape Hatteras Water Association on Hatteras Island in North Carolina. The purpose of the test drilling was to obtain information on the geologic and hydrologic conditions beneath the island. The data was collected to make a preliminary evaluation of the potential for developing a brackish raw water supply for reverse osmosis treatment on the island. The utility plans on developing a source of water that may ultimately generate as much as 3.0 million gallons per day (MGD) of potable water for public supply. Freshwater resources available in the water-table aquifer are currently being utilized to the maximum extent possible. Increased pumpage from the water-table aquifer is not allowable due to regulatory concerns over environmental impacts and the potential for saltwater intrusion into the wellfield. A test well was constructed near the existing water treatment plant as part of the investigation. The location of the test well and water plant are shown on Figure 1. The drilling and testing procedures utilized are described below.

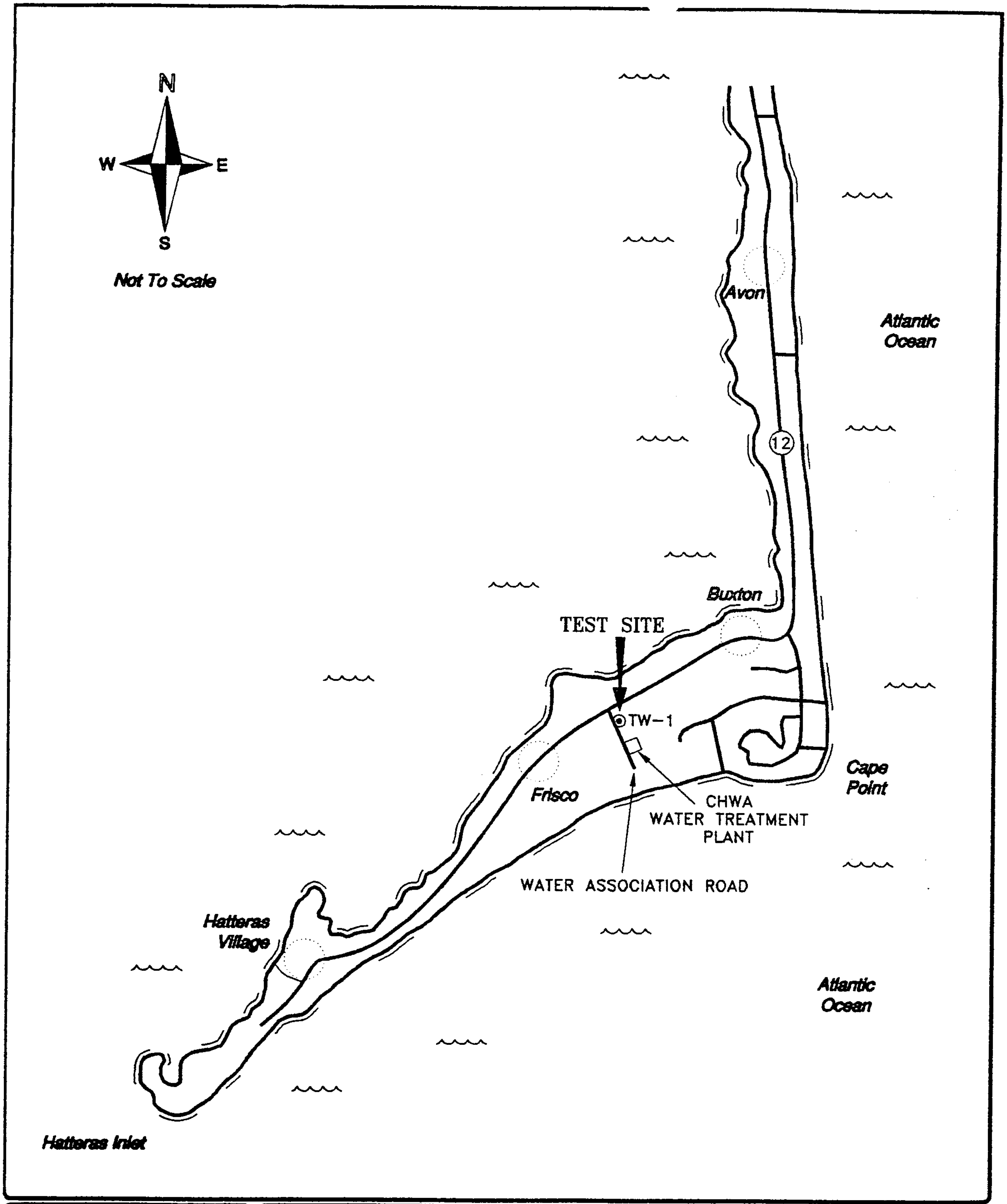
Drilling and Testing

Skippers Well Drilling from Leland, North Carolina was contracted by the Cape Hatteras Water Association to construct the test well. A hydrologist from MI supervised the drilling operation and collected formation samples for lithologic analysis. A geologist's log of the sediments encountered during drilling is enclosed. A stratigraphic column that illustrates the relative positions of the units penetrated is provided as Figure 2. Copies of the geophysical logs performed by the North Carolina Department of Environment, Health and Natural Resources are also included.

The mud rotary method was used to drill the test well. A detailed summary of the daily drilling activities is enclosed. Key points of the test drilling operation are discussed below.

The drilling contractor mobilized equipment to the site during the last week of March 1995 and set 10-inch diameter schedule 40 PVC surface casing to a depth of 49 feet below land surface. A 9½-inch diameter pilot hole was drilled below the surface casing under the direction of the hydrologist. A severe loss of circulation zone was encountered within a limestone unit at a depth of 255 feet below land surface which temporarily halted the drilling operation. It was decided to test the zone for water production potential by constructing an open hole well. Geophysical logs were performed on the borehole prior to setting casing.

A string of six-inch diameter schedule 80 PVC casing was set at 240 feet below land surface into the top of the limestone unit. The well was developed by compressed air pumping from within the casing. A large amount of drilling mud, shell, and rock cuttings were produced from the well during development. Development continued for



MISSIMER INTERNATIONAL

Pr Name: CAPE HATTERAS R.O. TEST WELL

Pr No. FH4-088 Date: 05/11/95

DWG No. FH4088S1.DWG Rev.No. 1

Groundwater
and
Environmental Services

FIGURE 1. SITE MAP SHOWING THE LOCATIONS OF THE CAPE HATTERAS WATER ASSOCIATION WATER TREATMENT PLANT AND TEST WELL TW-1.

approximately three hours at which point the produced water was relatively free of sediment.

A 5 hp electric submersible pump was set in the well and a pump test was conducted at a rate of 100 gpm. The pump test results are summarized in the enclosed Table 1. Inspection of the table indicates that the well has an extremely high productive capacity. A maximum drawdown of 0.53 feet was measured in the well during the test. The calculated specific capacity at a rate of 100 gpm is 189 gpm/ft. When corrected for head loss due to friction in the pipe, the specific capacity of the well may be as high as 300 gpm/ft at a pumping rate of 100 gpm.

Water samples were obtained from the well during air development and while pump testing. The samples were analyzed by staff with the Dare County Water Production Department for parameters critical to reverse osmosis plant design. Copies of the water quality analyses reports are enclosed. The dissolved chloride concentration of samples obtained while air developing was significantly higher than the dissolved chloride concentration of samples obtained while pumping. The rate at which water was produced during air development was much greater than the pumping rate of 100 gpm. This indicates that water within the aquifer is density stratified. During pumping it is likely that the water was produced primarily from the upper part of the aquifer. Dissolved chloride concentrations in samples obtained while pumping stabilized at 3800 mg/l. Air development samples had a dissolved chloride concentration of 4900 mg/l.

In general, the water quality within the zone tested was more saline than anticipated. It was decided to continue drilling in an attempt to locate a zone of better quality water. The limestone unit was present from 240 feet to a depth of approximately 440 feet below land surface where a green, sandy clay was encountered. The clay unit extended to approximately 560 feet below land surface at which point a sandstone lithology was encountered. The borehole was advanced to a total depth of 588 feet below land surface. Geophysical logs were conducted after reaching total depth. An attempt to obtain a water sample from the sandstone unit was made by running two-inch diameter PVC to the top of the zone with formation packers to form a seal. After numerous attempts to obtain a good, clean sample were unsuccessful, a one and a quarter inch diameter screen was run inside of the two-inch diameter pipe to the bottom of the hole. The screen was attached to a section of liner pipe which was sealed inside of the two-inch PVC with a packer. The final construction details of the well are shown on the enclosed Figure 3. The well would not clear up after continued air development and it appeared that obtaining a representative sample from this zone would not be possible from the test well. The dissolved chloride concentration of the samples that were obtained while air developing varied widely from approximately 4000 mg/l to 10,000 mg/l indicating that leakage from other zones was likely occurring. However, based on the data collected, it is assumed that water quality within the sandstone unit is at least as saline or more saline than the water quality within the upper limestone unit.

TABLE 1.

CAPE HATTERAS WATER ASSOCIATION
REVERSE OSMOSIS TEST WELL TW-1 PUMP TEST

Test Date: 4/10/95

Recorded By: Scott Manahan

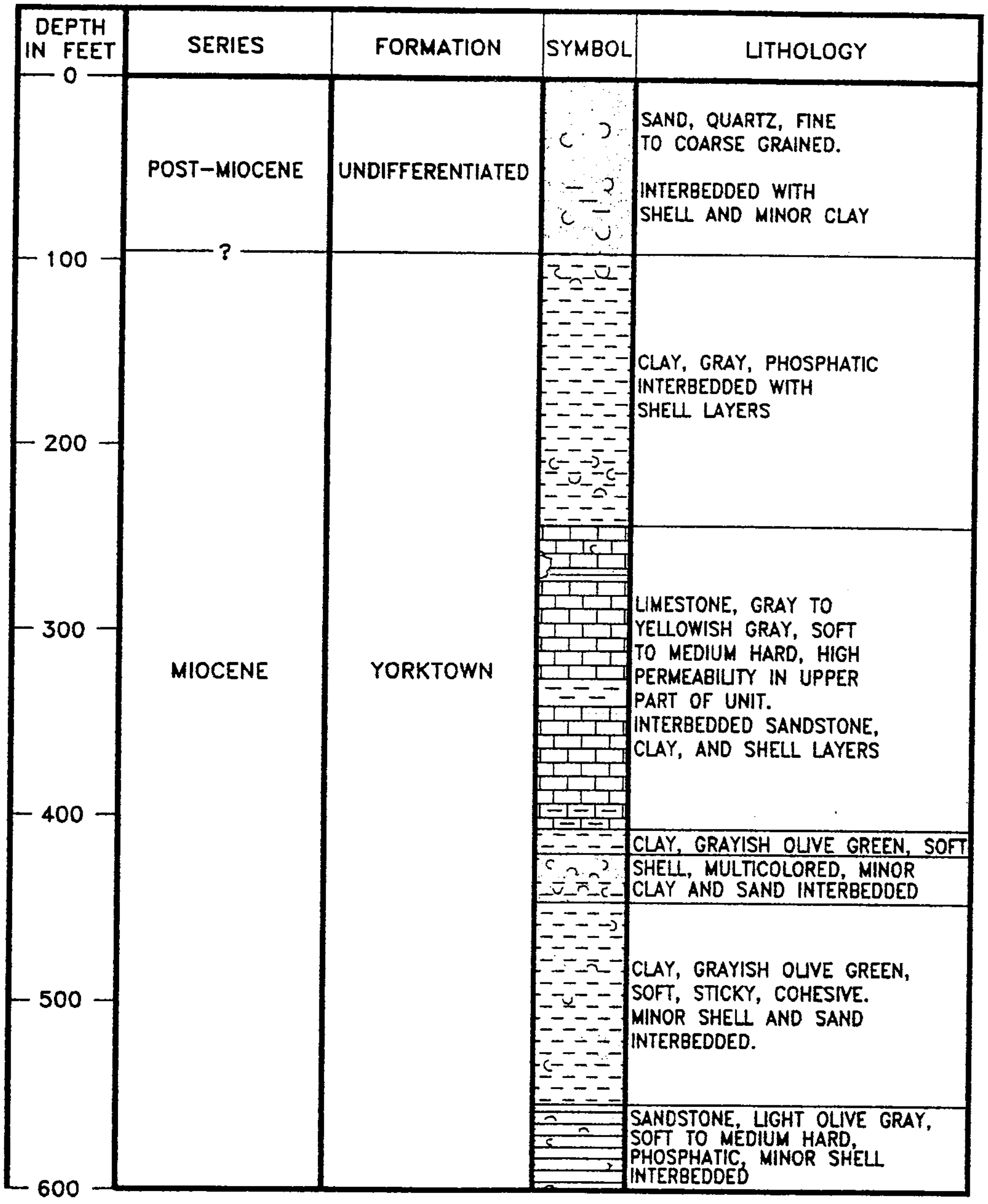
Static Water Level: 2.04 feet below measuring point (BMP) which is top of the PVC casing

Pumping Rate: 100 gpm

Elapsed Time (minutes)	Pumping Water Level (ft. BMP)	Drawdown (feet)
5	2.55	0.51
10	2.56	0.52
15	2.57	0.53
20	2.55	0.51
30	2.54	0.50
45	2.50	0.46
60	2.52	0.48
120	2.47	0.43
245	2.41	0.37
425	2.56	0.52

Specific Capacity = $\frac{100 \text{ gpm}}{0.53}$ = 189 gpm/ft

CAPE HATTERAS WATER ASSOCIATION
REVERSE OSMOSIS TEST WELL TW-1



MISSIMER INTERNATIONAL

Pr Name: CAPE HATTERAS R.O. TEST WELL

Pr No. FH4-088 Date: 05/12/95

DWG No. FH4088L1.DWG Rev.No. 2

Groundwater
and
Environmental Services

FIGURE 2. STRATIGRAPHIC COLUMN OF THE SEDIMENTS ENCOUNTERED DURING DRILLING OF THE CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1.

GEOLOGIST'S LOG OF CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1

Depth (feet)	Description
0-45	No sample. Driller reports mix of fine to coarse grained sand and shell with clayey sand at the bottom of the interval.
45-50	Shell, multicolored, interbedded with sand. Sand is quartz, medium to coarse, subrounded, with some pebble sizes.
50-60	Sand, quartz, grayish-black (N2), very fine to coarse, poorly sorted, subrounded, abundant shell, black (N1), good apparent permeability.
60-82	Sand and shell as above.
82-89	Shell, grayish-black (N2), interbedded with fine sand and sandy clay, medium gray (N5).
89-99	Shell as above with less clay.
99-110	Clay, dark gray (N3), sandy, fine medium gray (N5) sand interbedded, abundant shell.
110-120	Shell, very pale orange (10 YR 8/2), interbedded with fine sand and occasional medium gray (N5) clay.
120-135	Clay, medium dark gray (N4), interbedded with fine sand and shell, very pale orange (10 YR 8/2), low apparent permeability.
135-150	Clay, medium dark gray (N4), sandy, common shell and fine sand interbedded, low permeability.
150-160	Clay, as above.
160-175	Clay, medium gray (N5), sandy, soft, common shell.
175-196	Clay, medium gray (N5), soft, sticky, minor shell fragments, minor fine sand, finely phosphatic.

Continued:

GEOLOGIST'S LOG OF CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1

Depth (feet)	Description
196-215	Shell, multicolored, minor coarse sand, minor medium gray (N5) clay interbedded.
215-223	Shell, multicolored, interbedded with common medium gray (N5) clay, and fine to coarse grained quartz sand.
223-238	Clay, medium gray (N5), soft, sticky, common shell interbedded.
238-250	Limestone, medium dark gray (N4) to medium gray (N5), soft to medium hard, shell casts and molds, trace white lime mud, minor shell.
250-275	Limestone, medium gray (N5), soft to medium hard, casts and molds, common shell, high permeability. Interbedded with soft, medium dark gray (N4), friable sandstone. Severe loss of circulation zones encountered at 255 feet and 265 feet.
275-285	Limestone, medium dark gray (N4), sandy, soft to medium hard, friable, finely phosphatic, common shell fragments. Good apparent permeability.
285-294	Limestone, yellowish-gray (5 Y 8/1), sandy, medium hard, moderately well indurated, common shell fragments.
294-303	Limestone, yellowish-gray (5 Y 8/1), sandy, medium hard, moderately well indurated, casts and molds, common shell fragments, good apparent permeability.
303-313	Limestone, yellowish-gray (5 Y 8/1), soft, friable, clayey, poorly indurated, occasional shell fragments, fast rate of penetration, low to medium apparent permeability.
313-325	Limestone, as above.

Continued:

GEOLOGIST'S LOG OF CAPE HATTERAS WATER ASSOCIATION
REVERSE OSMOSIS TEST WELL TW-1

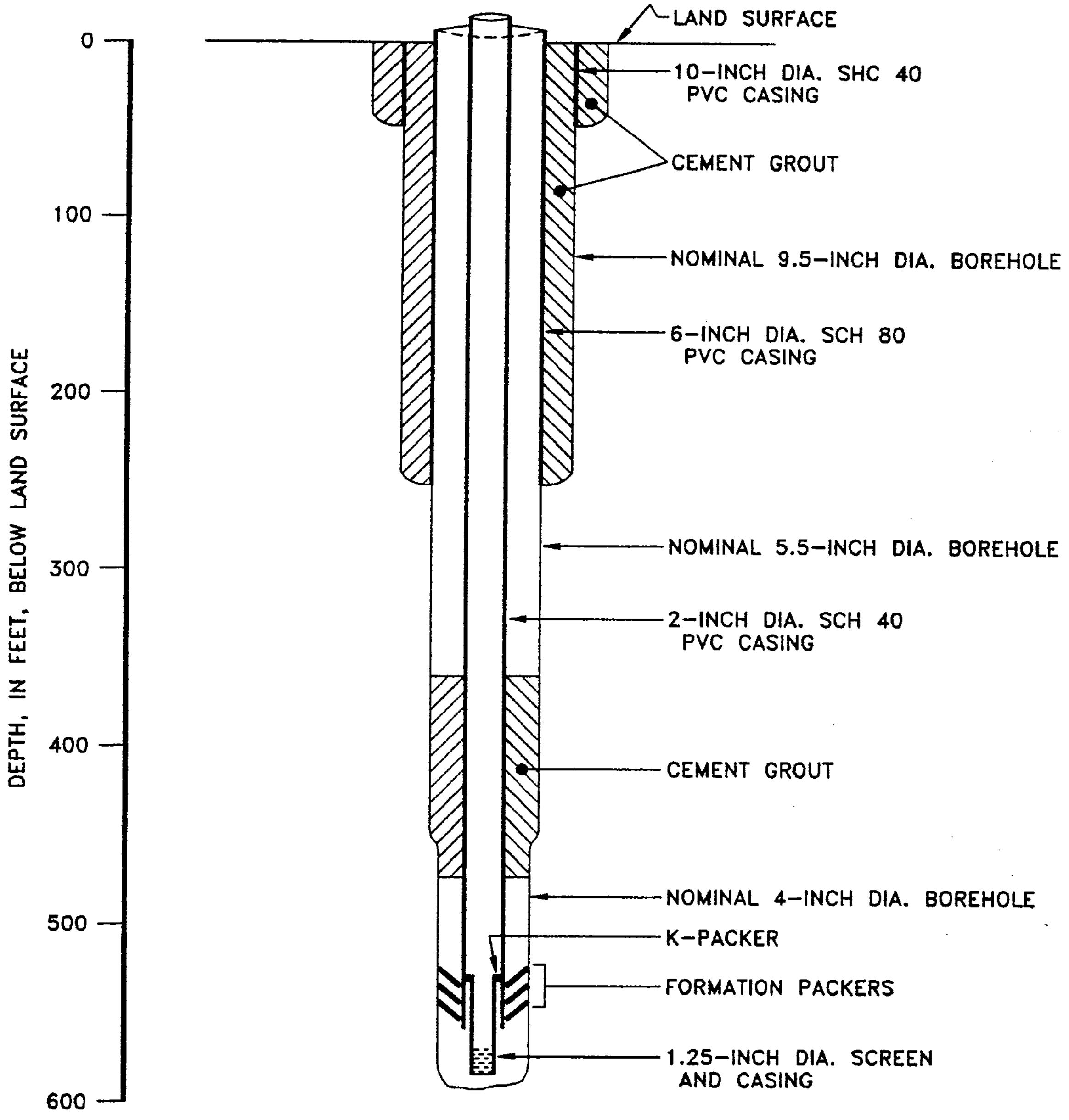
Depth (feet)	Description
325-334	Limestone, medium gray (N5), soft to medium hard, friable, poorly to moderately indurated, finely phosphatic, abundant shell fragments, minor white carbonate mud.
334-339	Limestone, as above.
339-345	Clay, brownish-gray (5 YR 4/1), soft, cohesive, carbonate, common shell and limestone fragments, low apparent permeability.
345-355	Sandy limestone, yellowish-gray (5 Y 8/1), soft to medium hard, poorly to moderately indurated, friable, minor shell. Low to medium apparent permeability.
355-366	Limestone, as above with minor clay interbedded.
366-376	Limestone, medium light gray (N6), soft to medium hard, poorly to moderately indurated, friable, abundant shell fragments, medium apparent permeability.
376-400	Limestone, yellowish-gray (5 Y 8/1), soft to medium hard, friable, occasional shell fragments, minor clay interbedded. Low to medium apparent permeability.
400-405	Limestone and clay, as above.
405-415	Clay, grayish-olive green (5 GY 3/2), soft, cohesive, common limestone and shell fragments.
415-421	Shell, multicolored, common limestone fragments, minor clay and sand interbedded.
421-442	Shell, multicolored, interbedded with coarse, rounded quartz sand. Formation taking fluid during drilling, medium to high apparent permeability.

Continued:

GEOLOGIST'S LOG OF CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1

Depth (feet)	Description
442-462	Clay, grayish-olive green (5 GY 3/2), soft, sticky, minor shell and limestone fragments, low permeability.
462-525	Clay, grayish-olive green (5 GY 3/2), soft, sandy, carbonate, minor shell interbedded, low permeability.
525-546	Clay, dusky yellowish-brown, soft, sandy, cohesive, trace shell. Sand is very fine grained.
546-557	Clay, as above.
557-567	Sandstone, light olive-gray (5 Y 5/2), soft to medium hard, friable, poorly to moderately indurated, finely phosphatic, shell lense at the top of the unit. Minor casts and molds, minor shell interbedded with sandstone, medium apparent permeability.
567-588	Sandstone, light gray (N7) to light brownish-gray (5 YR 6/1), soft to hard, friable, finely phosphatic (salt & pepper effect), minor shell fragments, minor casts and molds.

CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1



MISSIMER INTERNATIONAL

Pr Name: CAPE HATTERAS R.O. TEST WELL
Pr No. FH4-088 Date: 05/12/95
DWG No. FH4088W1.DWG Rev.No. 3

Groundwater
and
Environmental Services

FIGURE 3. SCHEMATIC DIAGRAM SHOWING THE FINAL CONSTRUCTION DETAILS OF THE CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL TW-1.

TABLE 2.

WATER QUALITY ANALYSES RESULTS
'E HATTERAS REVERSE OSMOSIS TEST WELL 1

Sample Drawn: 4/10/95
Date Analysis Completed: 4/10/95
Sample taken while air developing

Parameter	Concentration
P - Alkalinity as $CaCO_3$, mg/l	0
Total Alkalinity $CaCO_3$, mg/l	208
Bicarbonate as HCO_3, mg/l	253.6
Carbonate as CO_3, mg/l	0
Hydroxide as OH, mg/l	0
Total Hardness as $CaCO_3$, mg/l	1500
Calcium Hardness as $CaCO_3$, mg/l	540
Magnesium as $CaCO_3$, mg/l	960
Calcium as Ca, mg/l	216
Color	316
Silica as SiO_2, mg/l	23.4
Conductivity as umhos/cm	12,200
Iron, Fe, mg/l	.302
Potassium, K, mg/l	72.68
Copper, Cu, mg/l	3.93
Manganese, Mn, mg/l	.160
Phosphate as PO_4, mg/l	.380
Chloride as Cl-, mg/l	4,900
Fluoride as F, mg/l	.61
Nitrate as NO_3, mg/l	.05
Zinc as Zn, mg/l	.075
Chlorine (free Cl_2), mg/l	0
Lead as Pb, mg/l	---
Corrosivity	.25
pH	7.63
pHs	7.38
Turbidity, N.T.U.	35
Total Suspended Solids, mg/l	13.1
Total Dissolved Solids, mg/l	6100
Sulfate as SO_4, mg/l	264
Sodium as Na, mg/l (Est.)	1396.1
Sulfide as S, mg/l	0

TABLE 3.

WATER QUALITY ANALYSES RESULTS
'E HATTERAS REVERSE OSMOSIS TEST WELL ·1

Sample Drawn: 4/11/95
Date Analysis Completed: 4/11/95
Sample taken after pump testing at 100 gpm for seven hours

Parameter	Concentration
P - Alkalinity as $CaCO_3$, mg/l	0
Total Alkalinity $CaCO_3$, mg/l	210
Bicarbonate as HCO_3, mg/l	256
Carbonate as CO_3, mg/l	0
Hydroxide as OH, mg/l	0
Total Hardness as $CaCO_3$, mg/l	560
Calcium Hardness as $CaCO_3$, mg/l	224
Magnesium as $CaCO_3$, mg/l	336
Calcium as Ca, mg/l	81.65
Color	0
Silica as SiO_2, mg/l	17.2
Conductivity as umhos/cm	11,550
Iron, Fe, mg/l	.025
Potassium, K, mg/l	40.33
Copper, Cu, mg/l	4.78
Manganese, Mn, mg/l	.123
Phosphate as PO_4, mg/l	.172
Chloride as Cl-, mg/l	3,800
Fluoride as F, mg/l	.78
Nitrate as NO_3, mg/l	.21
Zinc as Zn, mg/l	.168
Chlorine (free Cl_2), mg/l	---
Lead as Pb, mg/l	---
Corrosivity	.39
pH	7.35
pHs	7.74
Turbidity, N.T.U.	.11
Total Suspended Solids, mg/l	3.2
Total Dissolved Solids, mg/l	5800
Sulfate as SO_4, mg/l	156
Sodium as Na, mg/l (Est.)	1882.29
Sulfide as S, mg/l	0

TABLE 4.

WATER QUALITY ANALYSES RESULTS
CAPE HATTERAS REVERSE OSMOSIS TEST WELL TW-1

April 11, 1995
Chloride and Conductivity samples taken while pump testing at 100 gpm

Time* (minutes)	Sample Number	Conductivity umhos/cm	Chloride mg/l
10	35	11700	3800
60	15	11410	3875
120	41	11610	3750
245	23	11630	3750
425	16	11630	3750

*Time since beginning pump test

SUMMARY OF DRILLING ACTIVITIES FOR THE CAPE HATTERAS WATER ASSOCIATION REVERSE OSMOSIS TEST WELL

- Skipper's Well Drilling mobilized equipment to the drill site in the last week of March 1995. The drillers set 49 feet of 10-inch diameter schedule 40 PVC surface casing and grouted.

- April 4, 1995 - Drillers begin drilling nominal 9½-inch diameter pilot hole under direction of a Missimer International hydrologist. The pilot hole was drilled to a depth of 255 feet below land surface when a major loss of circulation zone was encountered which halted drilling operations and caused the hole to collapse. The hole collapse caused the drill pipe to get stuck and it could not be removed.

- April 5, 1995 - The drillers spent the entire day trying to remove their drill pipe. They got the pipe out at 5PM and began mixing mud to continue drilling. The mud pump broke down so they shut down for the evening.

- April 6, 1995 - The drillers repaired their mud pump in the morning and continued drilling the pilot hole. Circulation was lost again at a depth of 255 feet below land surface. At this point the hydrologist directing the operation decided to construct an open hole well at this depth to assess water quality and potential yield of the zone.

- April 7, 1995 - The drillers regained circulation and cleaned out the hole in preparation for setting casing. Mike Vaught with the State of North Carolina Department of Environment, Health, and Natural Resources arrived at 10:30AM and ran geophysical logs on the hole. After logging was complete the drillers installed 240 feet of 6-inch diameter schedule 80 PVC casing.

- April 8, 1995 - Drillers cemented the casing in place with 70 bags of cement.

- April 10, 1995 - Drilled out the open hole of the well from 240 feet to 275 feet below land surface with a 5½-inch diameter bit. After drilling the open hole, the drill pipe was removed and the well was developed with compressed air from inside the casing. A 5-hp submersible pump was set in the well and a pump test was conducted for seven hours. Water quality samples were obtained by the hydrologist during air development and pumping and were analyzed by the Cape Hatteras Water Association and the Dare County Water Production Department. The dissolved solids concentration of the produced water was higher than anticipated, so it was decided by the hydrologist and the Cape Hatteras Water Association to continue drilling in an attempt to find another production zone of better quality water.

- April 11, 1995 - Drillers removed the test pump and ran a 1¼-inch diameter steel tremie pipe into the well to a depth of 251 feet below land surface. A slurry consisting of 12 bags of cement with 6% bentonite was spotted in the well at this depth in an attempt to seal off the loss of circulation zone. The slurry was allowed to cure for approximately 4 hours and an additional 8 bags of cement with 6% bentonite was pumped at a depth of 251 feet below land surface. Flow was noted out of the top of the casing while the second batch of cement was being pumped so it was assumed that the loss of circulation zone had been plugged.

- April 12, 1995 - The drillers continued with drilling of the pilot hole using a 5½-inch diameter bit. An additional loss of circulation zone was encountered at a depth of 265 feet below land surface. Two mud pits were pumped into the zone without getting returns. A slurry of 7 bags of cement was pumped in an attempt to seal off the loss of circulation zone. Since the extent and severity of the loss of circulation zone was unknown, it was decided to case off the zone with 4-inch steel pipe so that drilling could resume.

- April 18, 1995 - Drillers arrived at 6PM and ran 4-inch diameter steel pipe into the well to a depth of 252 feet below land surface.

- April 19, 1995 - Drillers continued drilling by rotating the 4-inch steel pipe and circulating through the center of the pipe. Drilled from 265 to 441 feet below land surface.

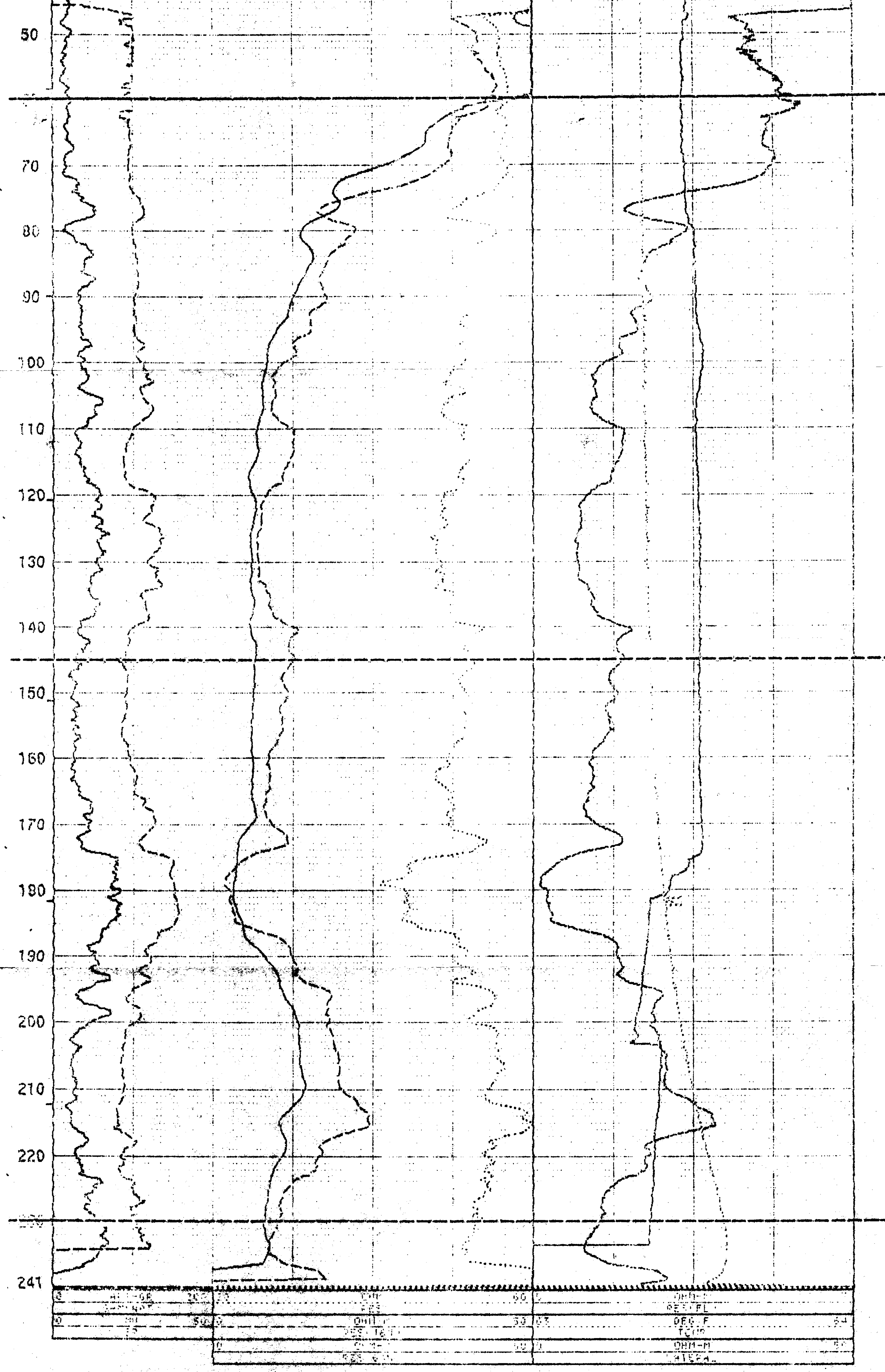
- April 20, 1995 - Continued drilling with the 4-inch diameter steel pipe to a depth of 462 feet below land surface which was the total amount of pipe available. To continue drilling, 2-inch diameter galvanized pipe equipped with a 4-inch diameter fabricated cutting tool was run inside of the 4-inch steel pipe. A 4-inch diameter hole was then drilled to a depth of 588 feet below land surface. A sandstone zone was encountered at a depth of approximately 560 feet below land surface. It was decided to complete an open hole well within this zone. The drillers removed the 4-inch steel casing and quit for the day.

- April 21, 1995 - The drillers removed the 2-inch diameter galvanized pipe in the morning. Mike Vaught, with the State of North Carolina Department of Environment, Health, and Natural Resources, arrived at 12:30PM and conducted geophysical logs on the well. After geophysical logging was complete, the drillers began running 2-inch diameter schedule 40 PVC casing in the well. The pipe was equipped with 3 rubber formation packers near the bottom and installed to a depth of 561 feet below land surface. After installing the pipe, compressed air was used to develop the well. The well produced very little water and did not clear up.

- April 22, 1995 - The drillers continued air development but the air line plugged up and then got stuck in the 2-inch diameter PVC casing. Attempts to remove the air line were unsuccessful so the drillers returned to their shop to get additional equipment.

- <u>April 25, 1995</u> - The drillers went inside of the 2-inch diameter PVC pipe with a ½-inch diameter steel pipe and were able to recover the stuck air line. Continued development failed to clear up the well. The assumption was made that the formation packers were not forming an adequate seal and that clay and sand from above the target zone were moving down the annulus between the borehole and 2-inch diameter casing. Cement was pumped through a tremie pipe from a depth of 460 feet in an attempt to isolate the target zone from overlying layers.

- <u>April 26, 1995</u> - After allowing the cement to cure, air development was continued in an attempt to clear up the well. The well did not clear up so a 1¼-inch diameter PVC screen was set on a PVC liner and pushed down to the bottom of the well. The screen length was 10 feet followed by 40 feet of 1¼-inch pipe with a packer inside the 2-inch PVC to form a seal. Air development was continued after the screen was installed. The produced water did not clear up and the dissolved chloride concentration of samples obtained while air developing varied widely from approximately 4000 to 10,000 mg/l indicating that leakage from other zones was still occurring. An attempt was made to pump the well in order to get a representative water sample from the sandstone unit. The well would not yield any water using a centrifugal pump because of a low static water level. It was concluded that sediments above the sandstone unit had bypassed the formation packers and filled in around the screen. This made obtaining a sample impossible so work on the well was terminated.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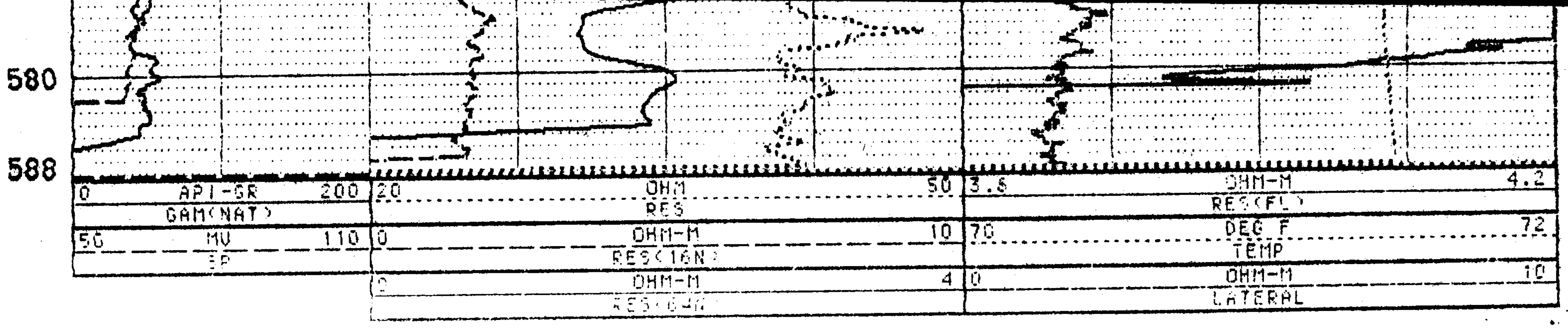
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DEPARTMENT OF ENVIRONMENT HEALTH
AND NATURAL RESOURCES
DIVISION OF ENVIRONMENTAL MGMT.
GROUNDWATER SECTION
512 NORTH SALISBURY STREET
ARCHADALE BLDG., ROOM 826
P. O. BOX 27687, RALEIGH NC 27611

RO - Test Well # 1

COMPANY : Cape Hatteras Water Associatin
WELL : RO - Test Well # 1
LOCATION/FIELD : North Frisco - Ocean Side
COUNTY : Dare
STATE : NC
SECTION :

OTHER SERVICES:
-
-

TOWNSHIP :
RANGE :

DATE : 04/21/95
DEPTH DRILLER : 585
LOG BOTTOM : 580.40
LOG TOP : 7.90

PERMANENT DATUM : msl
ELEV. PERM. DATUM: 0.00
LOG MEASURED FROM: Ground
DRL MEASURED FROM: -

ELEVATIONS
KB :
DF :
GL : 5

CASING DRILLER : 240
CASING TYPE : PVC
CASING THICKNESS: 80

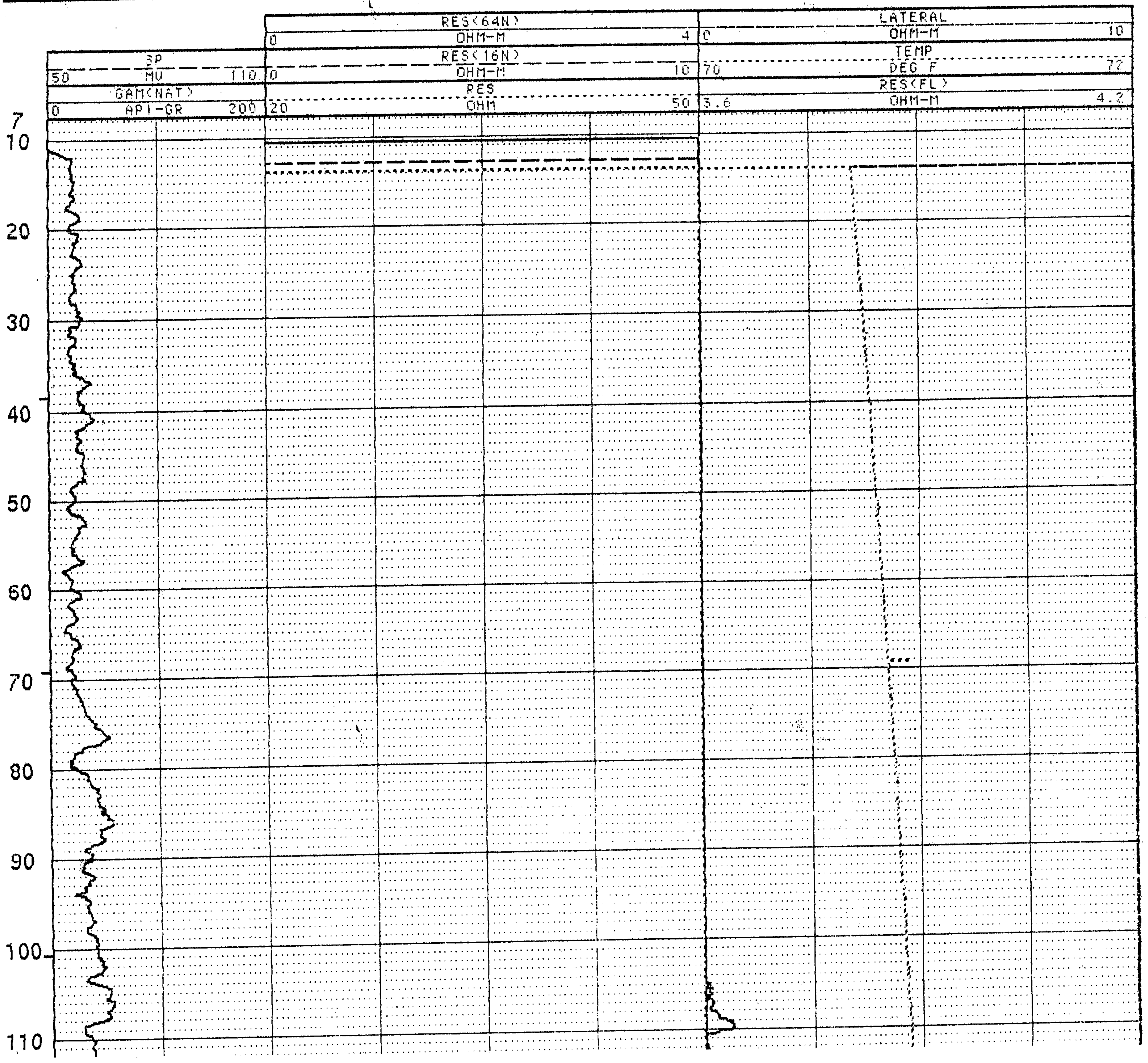
LOGGING UNIT : 0111
FIELD OFFICE : CD
RECORDED BY : mike vaught

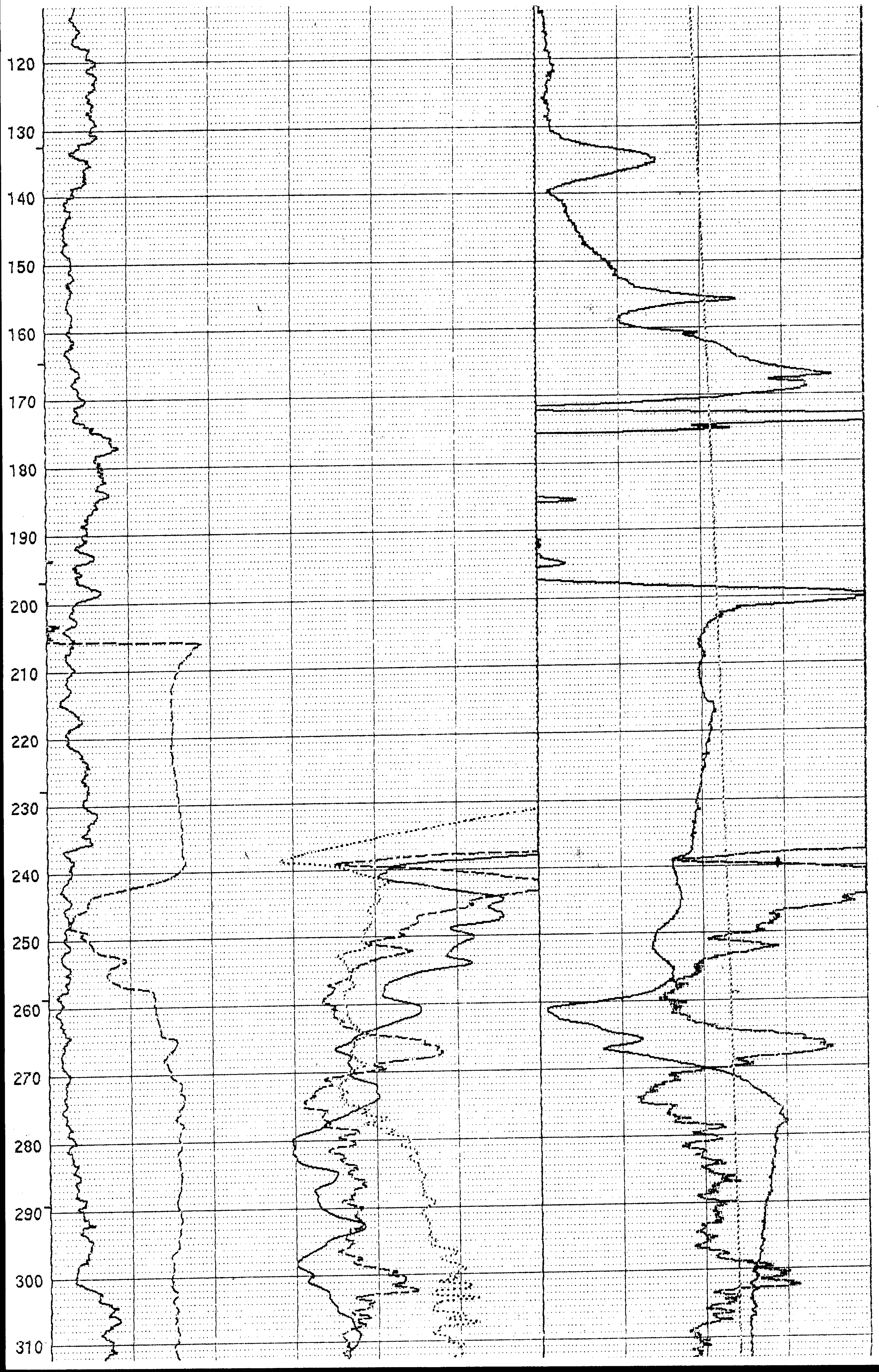
BIT SIZE : 4
MAGNETIC DECL. :
MATRIX DENSITY :
FLUID DENSITY : 9
NEUTRON MATRIX :
REMARKS :
From Hwy 12 in North Frisco Take Water Assoc Rd on ocean side approx 100yd
Csg to 240, 5.5" hole to 462, then 4" hole to 585. lost circ @ 265 sleve drill

BOREHOLE FLUID : Ben
RM :
RM TEMPERATURE :
MATRIX DELTA T :
FLUID DELTA T :

FILE : ORIGINAL
TYPE : 9041A
LOG : 9
PLOT : 9041A 0
THRESH: 999999

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS

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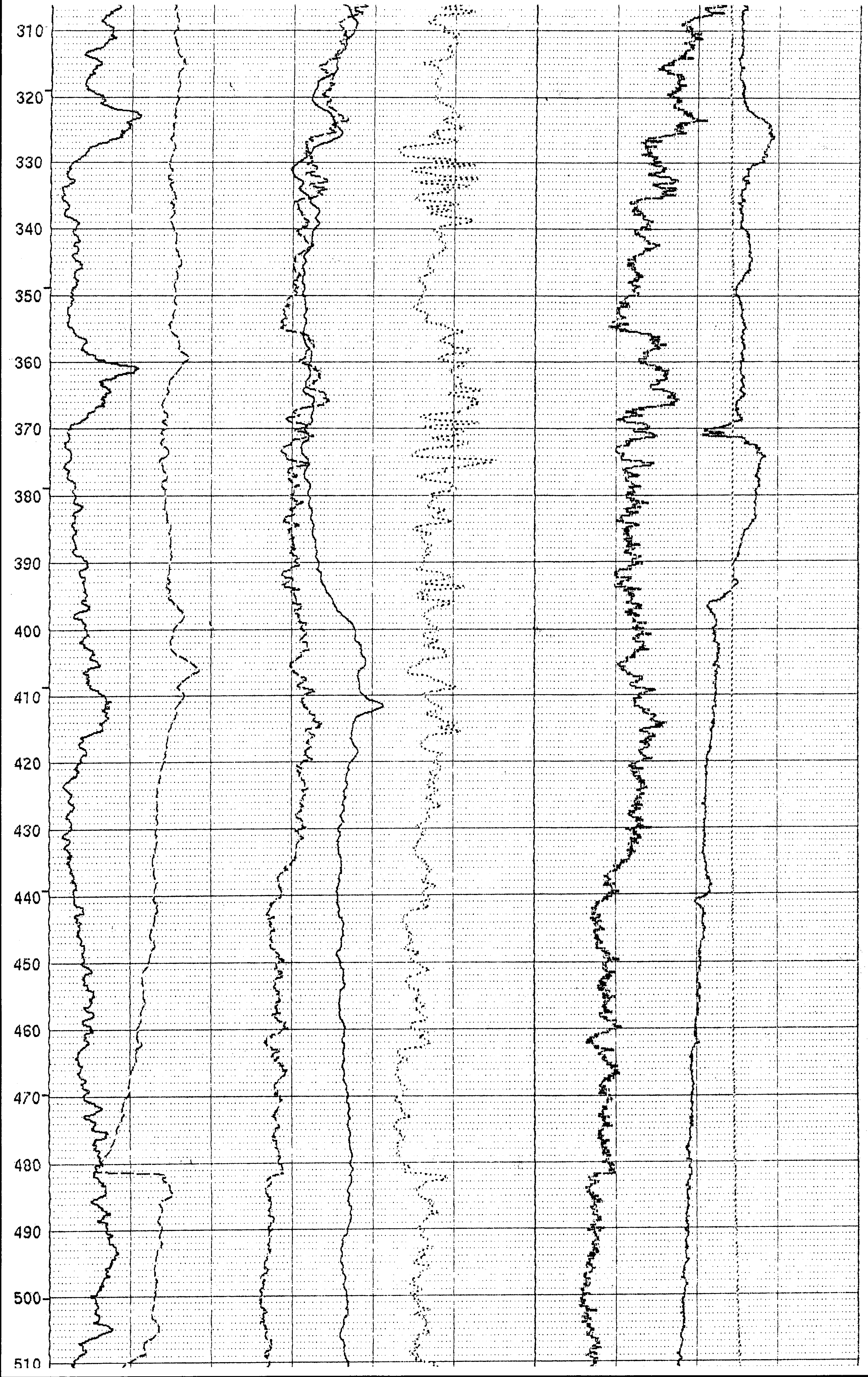
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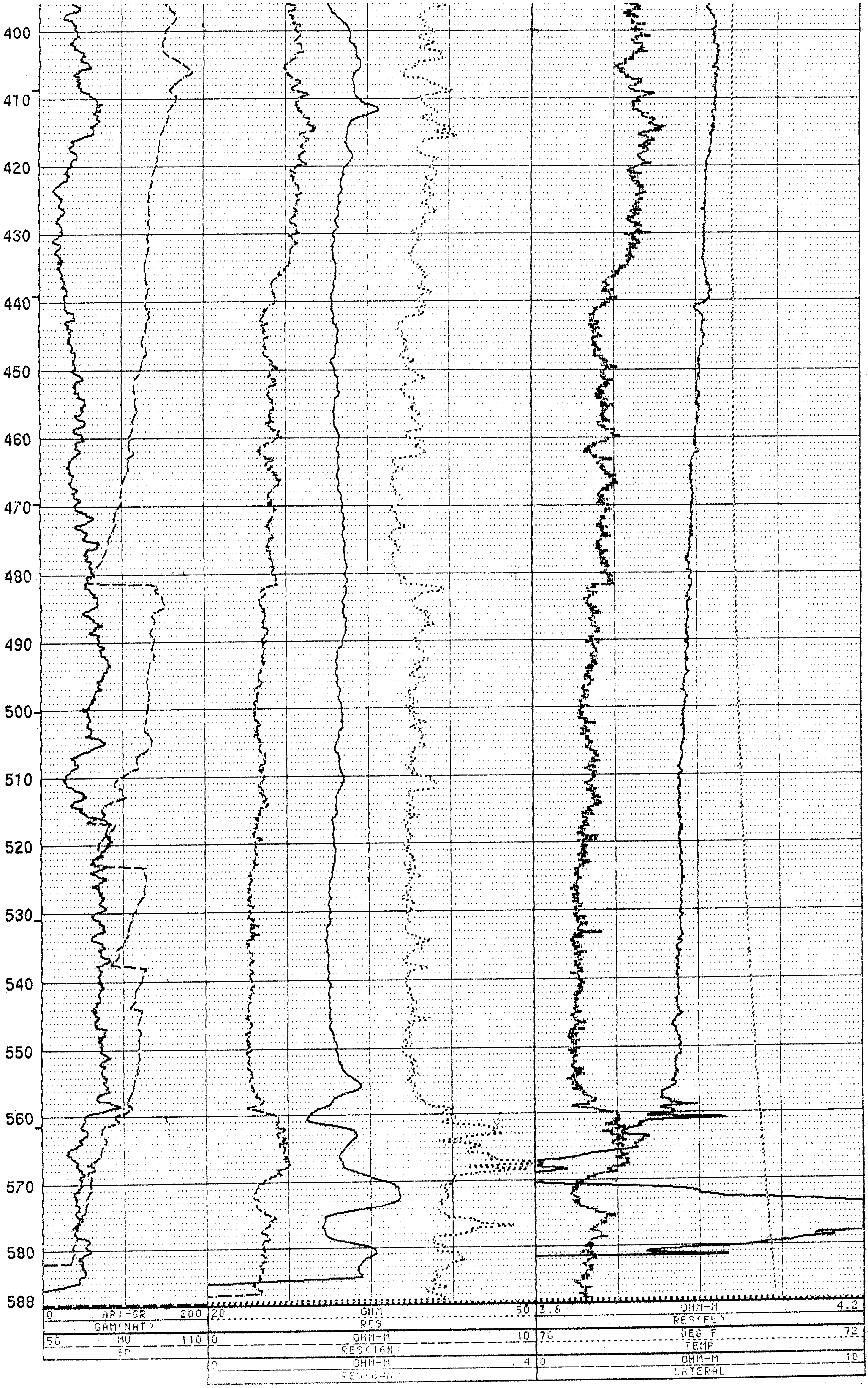
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RES
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RES(64N)
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RES(FL)
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