AQUIFER TEST

SMUGGLERS' VILLA

ORCAS ISLAND

SAN JUAN COUNTY, WASHINGTON

BY

P. GRIMSTAD

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PURPOSE OF THE INVESTIGATION

This study was initiated in response to a memorandum of November 8, 1972 from Duane E. Wegner, Resource Management Supervisor of the Northwest Regional Office, Department of Ecology, requesting the evaluation of a ground-water application north of the community of Eastsound on Orcas Island. The application was for an amount of withdrawal which seemed excessive and caused concern that the lowering of the water level would lead to contamination of the aquifer by sea water encroachment.

LOCATION AND TOPOGRAPHY

Smugglers' Villa, in SW¼NE¼ Sec. 11, T.37 N., R.2W.W.M. and about one mile north of Eastsound, is a condominium type development on the north shore of Orcas Island (Fig.1). To date a boat basin extending inland approximately 1200 feet from the Straits of Georgia and 10 dwellings each consisting of two units have been constructed (Fig.2). Submitted plans call for the building of 28 additional units. The wooded land has an elevation of 25 feet or less above sea level and slopes westerly and northwesterly to the edge of the boat basin.

GEOLOGY AND GROUND WATER

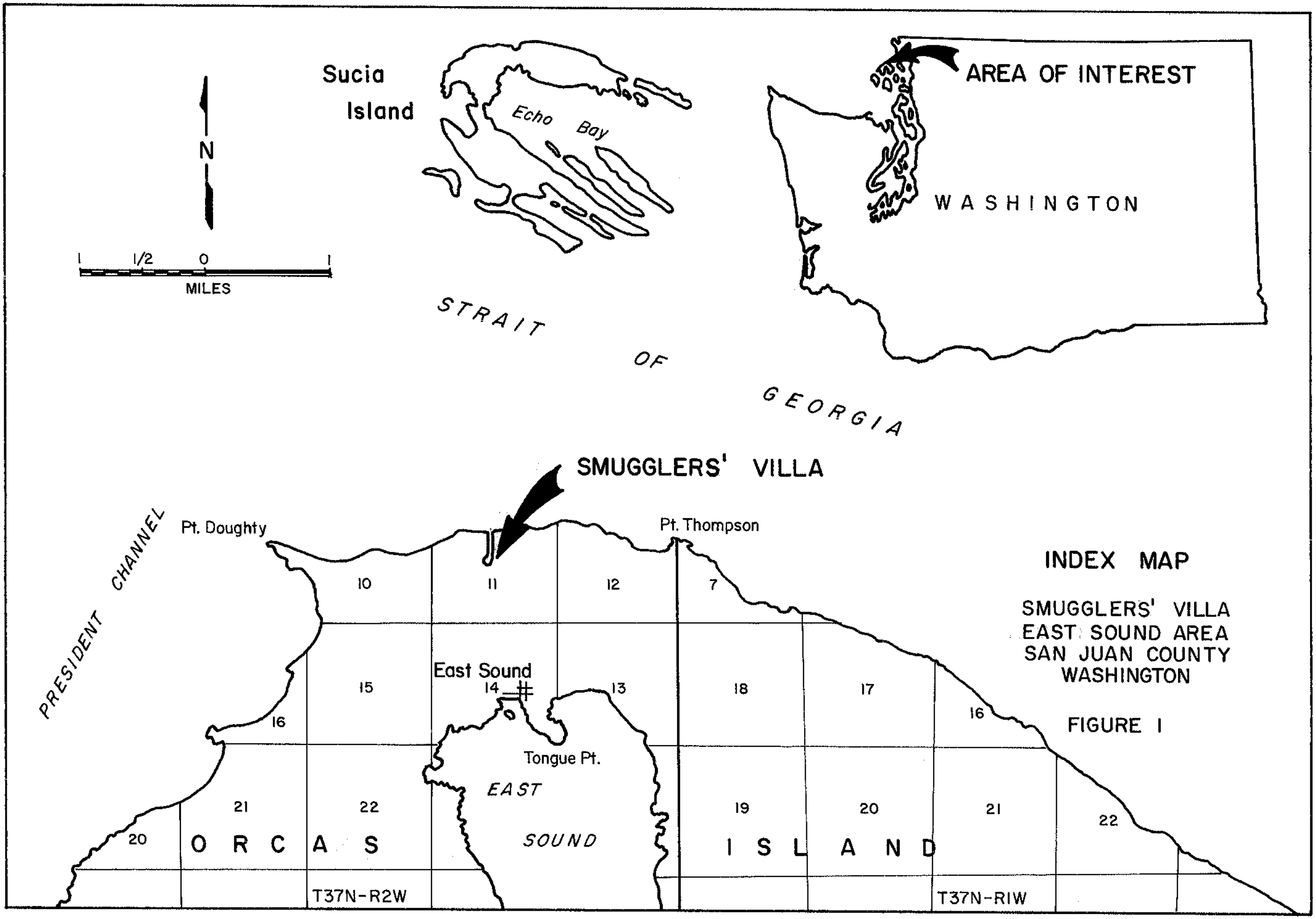
Two lithologic units are important to the occurrence of ground water in the general area of Eastsound: consolidated rocks and unconsolidated to poorly consolidated sediments. The consolidated rocks (bedrock) make up the nearby hills and underlie the area of interest. These consist of Mesozoic sedimentary and igneous rocks which are indurated and contain very little pore space. Therefore, the hydraulic conductivity is low and the rock does not hold or transmit water except along fractures. Well yields, if any, from this unit are generally low (a few gallons per minute) and are barely adequate for domestic supply.

The unconsolidated rocks overlie the bedrock and are of Quaternary age. They consist of glacial, fluvial, and lacustrine deposits of clay, silt, sand, and gravel. The sands and gravels are the major water-bearing materials. Clays and tills, where present, are largely impermeable and serve as barriers to the movement of ground water.

Recharge is primarily from precipitation which averages about 29 inches annually. Infiltration occurs through the overlying soil and till, where present, to the aquifer. Additionally, some subsurface transmittal of water probably occurs from the bedrock via fractures directly into the aquifer.

AQUIFER TESTING

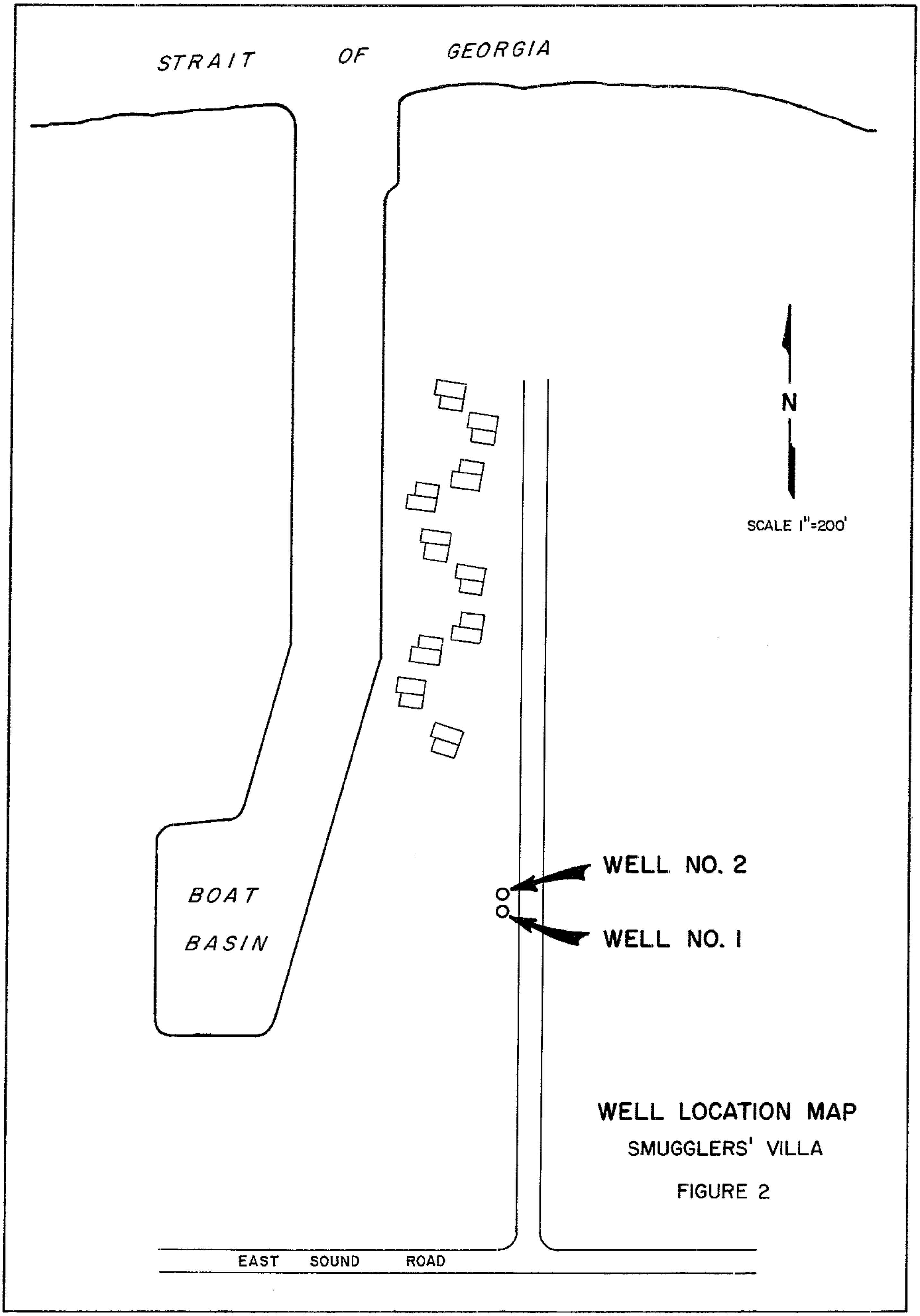
Data from the two wells at Smugglers' Villa were used in this evaluation (Fig. 2). According to information submitted with the ground-water application, Well No. 1 which is southernmost, encountered two feet of soil, 16 feet of hardpan (till) and 20 feet of water-bearing



INDEX MAP

SMUGGLERS' VILLA
EAST SOUND AREA
SAN JUAN COUNTY
WASHINGTON

FIGURE 1



WELL LOCATION MAP
SMUGGLERS' VILLA
FIGURE 2

sand. Well No. 2 which is 23 feet north of the first well and reportedly 40 feet deep, encountered a similar sequence of sediments. The aquifer is artesian and the average water level is about 2.5 feet above the top of the water-bearing sand.

Both wells are cased with 36-inch concrete tile and only the lowermost 2½ feet is perforated. A 30-inch inner casing extends inside the concrete tile liner almost to the bottom of the well and is cemented in place from ground surface to 20 feet. From this point the annulus is gravel packed. The wells obtain water only through the lowermost end of the casing. Five horsepower and 2.5 horsepower pumps have been installed on No. 1 and No. 2 wells respectively. A day was spent prior to the pumping test measuring water levels in well No. 2 and comparing these with the tidal fluctuations as measured from a reference point (coin attached to the dock) at the boat basin. The water levels in the wells rise and fall with the rise and fall of the tide and the water-level change is about .05 foot per foot of change in tide. The lag time for a high tide is about three hours and 40 minutes.

At 0900 hours on November 29, 1972, the pump was started at the No. 2 well and the flow was measured at 35 gallons per minute (gpm) as determined by timing the filling of a container of known volume. Within 24 minutes the water level in the well had dropped to 29.2 feet below the pump house floor and below the pump intake. The pumping was stopped and the well was allowed to recover until 1100 hours when pumping was started at a rate of 10 to 12 gpm. This rate was continued for 24 hours at which time the pump was shut down and recovery information was collected for another 24 hours. The drawdown and recovery data for the observation well (well No. 1) are shown in Figures 3 and 4. Additionally, because of the effect of tidal fluctuations on the water level in the wells, hourly measurements were made from the boat basin dock to sea level. These data are also shown on the figures.

Although the existing aquifer conditions do not satisfy all of the requirements stipulated for the application of the Theis nonequilibrium equations, these were used and will give approximate values which will assist in the evaluation of the aquifer.

The superposition of tidal effects upon the time-drawdown and time-recovery curves complicates the interpretation of the data. However, a comparison of the two curves points to a common slope or a similar change in drawdown per log cycle. Using the Jacob modification of the Theis nonequilibrium formula, $T=264Q/\Delta s$ (Q=pumping rate-11 gpm, Δs= change in drawdown in feet per log cycle - 0.95 foot), the value of T (transmissivity) is 3,000 gallons per day per foot.

To determine water levels in the observation well as they relate solely to actual recovery (Fig. 4), the deviations in the curve caused by the tides must be removed. Noting that an incoming tide causes an increase and an outgoing tide causes a decrease in the water level in the well, the divergence extending from 65 minutes to 300 minutes ABR (after beginning of recovery) was caused by the incoming tide. As indicated by previous data, the well response lags about 3 hours 40 minutes (220 minutes) behind the tide; therefore the point of high tide (65 minutes ABR) corresponds to a point at 65 plus 220 equals 285 minutes ABR on the composite time-recovery curve. That portion of the composite curve extending from 150 minutes to 285 minutes corresponds to an interval during which the tide is high and the change in tidal level is minimal. Therefore, the slope of this portion of the curve closely approximates the slope of the true time-recovery curve. If aquifer characteristics remain constant, that is, no recharge or barrier boundaries are encountered and the well is still recovering, the composite curve at the next high tide of like magnitude should fall on the extension of the slope line (A-B). At the next high tide, which occurs at 1025 minutes, the slope line and composite curve are about 0.1 foot apart which is an acceptable check when one considers that the second high tide is less than the first.

However, the measured water level in the well is a composite of the high tide effect and aquifer recovery. Another line, C-D, which is parallel to line A-B, passes through the deflection of the composite time-recovery curve caused by the low tide at about 550 minutes. A line E-F between these two extremes approximates the true time-recovery curve. This line is parallel to and spaced between the lines A-B and C-D such that the ratio between the perpendicular distances from the line E-F to the lines A-B and C-D is the same as the ratio of the difference between the high tide at 65 min. ABR and MSL (9 feet below M.P. on dock) and low tide at 550 minutes ABR and MSL. The true water level in the well when recovery measurements began is also needed to determine the recovery data. Taking into account the time lag, the test was begun approximately at the time at which the water level in the well (18.30 feet) reflected the effect of mean sea level. This is the point at which tidal effects upon the water level in these wells are near zero and, therefore, this depth was used as the true level for the beginning of the recovery test.

Based upon the time-recovery data derived from the above approximations (Table 1), 1440 r^2/t - r= distance in feet between the pumped well and observation well (23 feet), t= time since recovery test began in minutes- vs. recovery in feet, were plotted and matched with the Theis type curve. A transmissivity of 2900 gpd per foot was determined which compares favorably with the figure 3000 arrived at by using the Jacob method. A coefficient of storage of 0.05 was established, and together with an average transmissivity value of 3000, was used to calculate time-distance-drawdown data (Table 2) which are shown graphically in Fig. 5.

Because of the proximity of the Smugglers' Villa wells to the ocean, the possibility of salt water invasion and possible well contamination should be taken into account in well development. The Ghyben-Herzberg theory covers the relationship between fresh water and salt water and states that for every foot of fresh water above mean sea level the thickness of the fresh water lens resting on the salt water is about 40 feet. Although this is not entirely correct because the theory is based on hydrostatic conditions which are the exception rather than the rule, studies by others indicate that the factor of 40 is a close approximation.

Using the tidal data collected at the nearest reference station, Port Townsend, and assuming that the time and tidal differences between this station and Echo Bay on Sucia Island are applicable to Smugglers' Villa, mean sea level is 9 feet below the reference marker (coin) located on the dock at the boat basin and 21 feet below the floor of the existing pump house.

CONCLUSIONS

The amount of water which can be withdrawn without producing undesirable effects is limited in the Smugglers' Villa area by the proximity of the wells to the salt water and the productivity of the aquifer. As discussed above, withdrawing the water in the wells to a level below sea level will eventually result in upward coning of brackish water and contamination of the fresh water lens. Mean sea level is equivalent to 21 feet below the pump house floor. To prevent lowering of the water in the wells below this critical depth, it is recommended that the pump intakes be installed such that no withdrawal is possible below this level. Further, on the basis of aquifer data, a high pumping single well is of little value as drawdown is rapid and the critical level of 21 feet is reached in a short time. During the test a pumping rate of 35 gpm caused a water level decline from 15.25 feet below the pump house floor to 21 feet in 9 minutes.

From the above, it is obvious that a multiple well system with small individual pumping rates is the most feasible method by which the withdrawal time can be extended and the amount of withdrawal can be safely increased. The standing water level in the Smugglers' Villa wells is about 15 feet below the pump house floor. Therefore, the water levels in the well can be lowered 6 feet. The time-distance-drawdown curves (Fig. 5) give an approximation of the spacing of the wells and the time in days that one or more wells can be pumped at 11 gpm. For example, a well which is pumped continuously for 10 days would have a drawdown at the well site of approximately 5 feet. A well located 100 feet away could also be pumped continuously for 10 days and the drawdown at each of the wells would be 6 feet or approximately, to the critical level. Further, two wells located approximately 400 feet apart can be pumped continuously for 50 days before the water level in the two wells would reach the critical depth. The above is based on the assumption that the potentiometric surface in both wells at the beginning of pumping is at the same elevation, that the wells are in the same uniform aquifer, and that future wells are drilled to the same depth and completed in the same manner as the existing wells.

Future wells in the Smugglers' Villa development should penetrate the entire aquifer and should be completed so that as much of the penetrated aquifer as possible is open to the wells. The latter will decrease the entrance velocity which means the head loss will be less, the drawdown in the well at a given pumping rate will be minimized, and the pumping can be continued for a longer period of time before the critical level is reached.

REFERENCES
(Not referred to in text)

De Wiest, Roger J.M., 1965, Geohydrology: John Wiley and Sons, Inc., New York, 366p.

Washburn, R. L., 1954, Preliminary Investigation of Ground Water in the Eastsound Area, Orcas Island, San Juan County, Washington: U.S. Geol. Survey open file report, 25p.

APPENDIX

Tables 1 and 2

Figures 3, 4 and 5

AQUIFER TEST DATA - OBSERVATION WELL - RECOVERY
(Approximation - Line E-F, Figure 4)

r = 23' M.P. (measuring point) = 1.4 feet above pumphouse floor

Date	Time	Minutes	$\frac{1440\ r^2}{t_{(minutes)}}$	Water Level (above M.P.)(Feet)	Recovery
11-30-72	1100	0		18.30	0
	1150	50	1.52×10^4	17.25	1.05
		55	1.38×10^4	17.20	1.10
	1200	60	1.27×10^4	17.18	1.12
		65	1.17×10^4	17.13	1.17
		70	1.09×10^4	17.10	1.20
		80	4.5×10^3	17.05	1.25
		90	8.4×10^3	17.00	1.30
		100	7.6×10^3	16.95	1.35
	1300	120	6.3×10^3	16.88	1.42
		150	5.1×10^3	16.78	1.52
	1400	180	4.2×10^3	16.72	1.58
		210	3.6×10^3	16.65	1.65
	1500	240	3.2×10^3	16.59	1.71
		270	2.8×10^3	16.55	1.75
	1600	300	2.5×10^3	16.50	1.80
		330	2.3×10^3	16.46	1.84
	1700	360	2.1×10^3	16.43	1.87
		390	2.0×10^3	16.39	1.91
	1830	450	1.7×10^3	16.33	1.97
		510	1.5×10^3	16.27	2.03
	2030	570	1.3×10^3	16.23	2.07
		630	1.2×10^3	16.20	2.10
	2230	690	1.1×10^3	16.16	2.14
		750	1.02×10^3	16.13	2.17

Table 1

Date	Time	Minutes	$\frac{1440\ r^2}{t_{(minutes)}}$	Water Level (Above M.P.)(Feet)	Recovery
12-01-72	0030	810	9.4×10^2	16.09	2.21
		870	8.8×10^2	16.06	2.24
	0230	930	8.2×10^2	16.03	2.27
		960	7.9×10^2	16.01	2.29
	0400	1020	7.5×10^2	15.99	2.31
		1080	7.1×10^2	15.97	2.33
	0600	1140	6.7×10^2	15.95	2.35
		1200	6.3×10^2	15.92	2.38
	0800	1260	6.0×10^2	15.90	2.40
		1320	5.8×10^2	15.88	2.42
	1000	1380	5.5×10^2	15.87	2.43
	1100	1440	5.3×10^2	15.85	2.45

Table 1 (Cont.)

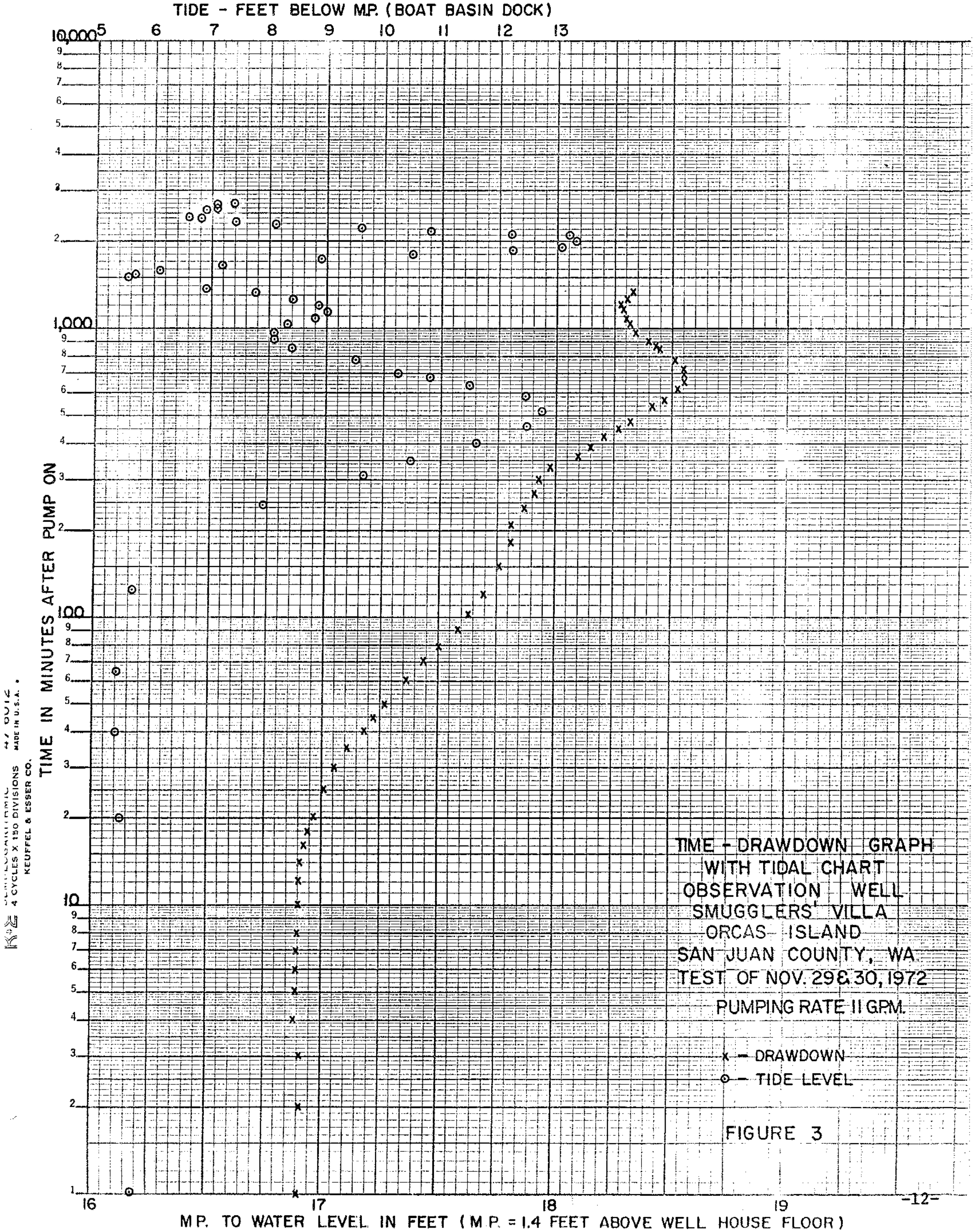
DRAWDOWN-DISTANCE-TIME DATA

$$u = \frac{1.87r^2S}{Tt_{days}} \qquad D = \frac{114.6\ QW(u)}{T}$$

S = 0.05 T = 3000 gpd/ft. Q = 11 gpm

	Time (days)	u	W(u)	D
One foot	1	3.12×10^{-5}	9.80	4.1
from	10	10^{-6}	12.10	5.1
pumped	100	10^{-7}	14.40	6.1
well	1000	10^{-8}	16.71	7.0
Ten feet	1	3.12×10^{-3}	5.20	2.2
from	10	10^{-4}	7.49	3.1
pumped	100	10^{-5}	9.80	4.1
well	1000	10^{-6}	12.10	5.1
One	1	3.12×10^{-1}	0.88	.4
hundred	10	10^{-2}	2.92	1.2
feet from	100	10^{-3}	5.20	2.2
pumped	1000	10^{-4}	7.49	3.1
well				
One	1	3.12×10^{1}	----	---
thousand	10	10^{0}	.01	---
feet from	100	10^{-1}	.88	.4
pumped	1000	10^{-2}	2.92	1.2
well				

Table 2



TIDE - FEET BELOW M.P. (BOAT BASIN DOCK)
TIME IN MINUTES AFTER PUMP ON
M.P. TO WATER LEVEL IN FEET (M.P. = 1.4 FEET ABOVE WELL HOUSE FLOOR)
TIME - DRAWDOWN GRAPH
WITH TIDAL CHART
OBSERVATION WELL
SMUGGLERS' VILLA
ORCAS ISLAND
SAN JUAN COUNTY, WA.
TEST OF NOV. 29 & 30, 1972
PUMPING RATE 11 GPM.
x — DRAWDOWN
⊙ — TIDE LEVEL
FIGURE 3
SEMI-LOGARITHMIC
4 CYCLES X 150 DIVISIONS
KEUFFEL & ESSER CO.
MADE IN U.S.A.

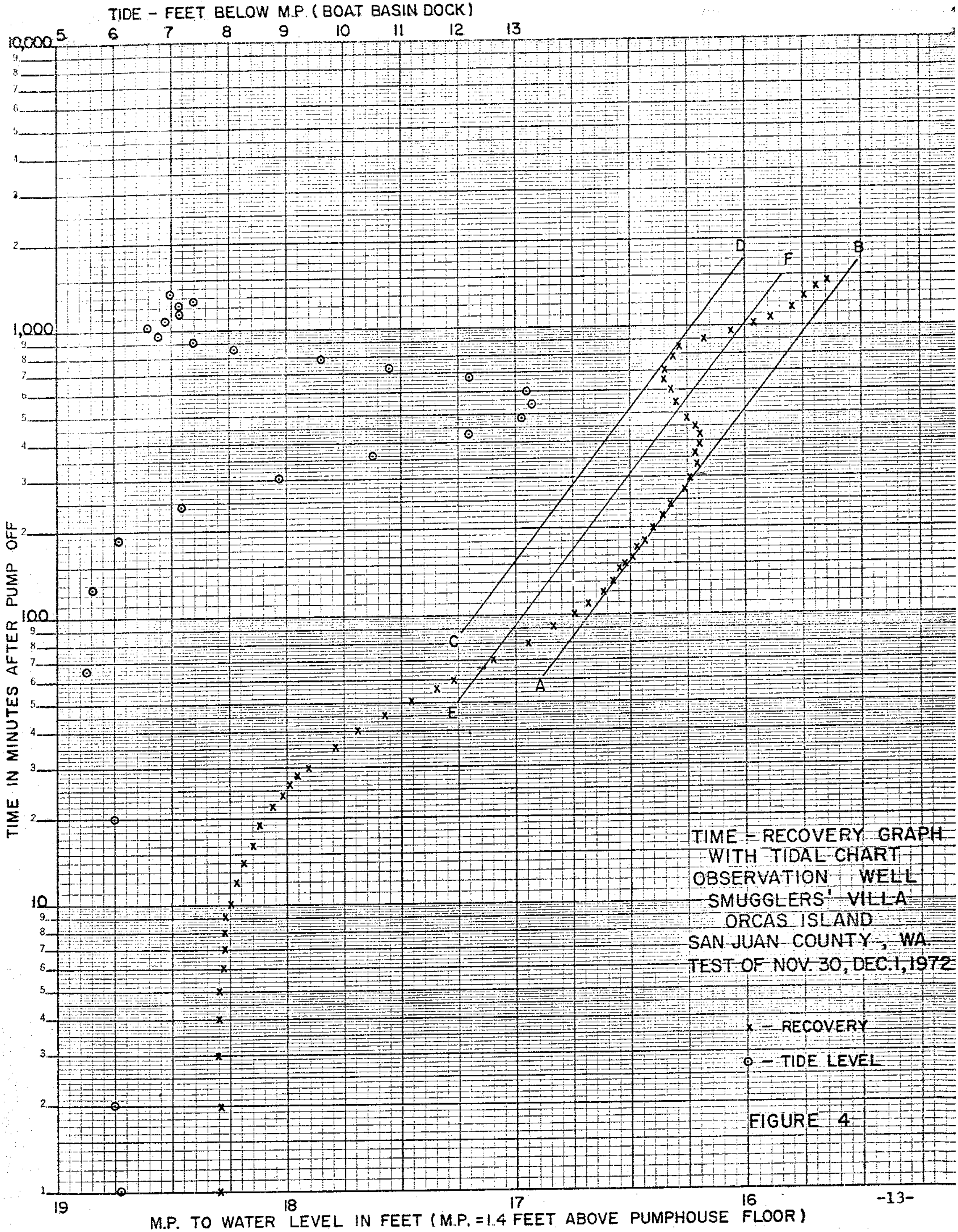
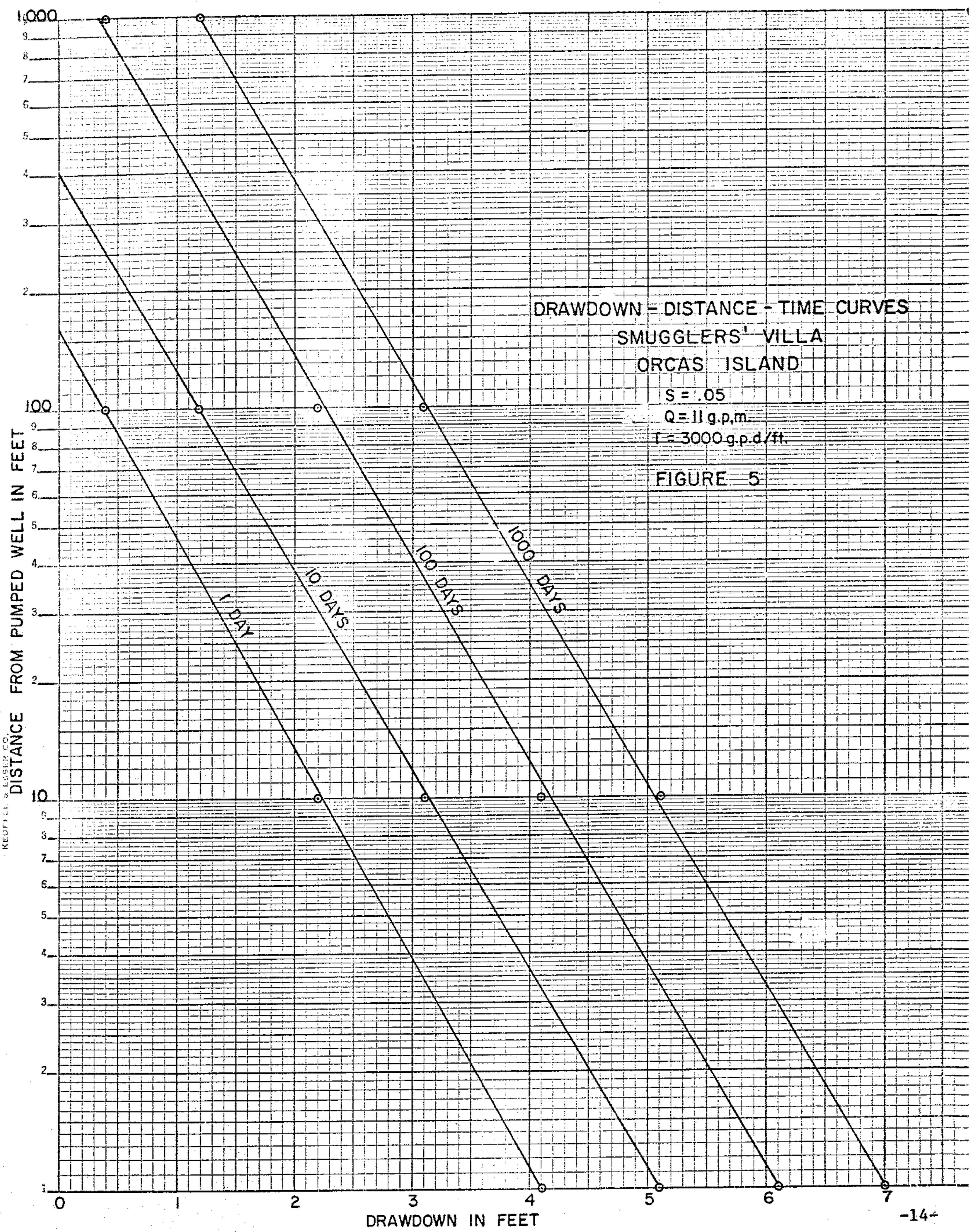
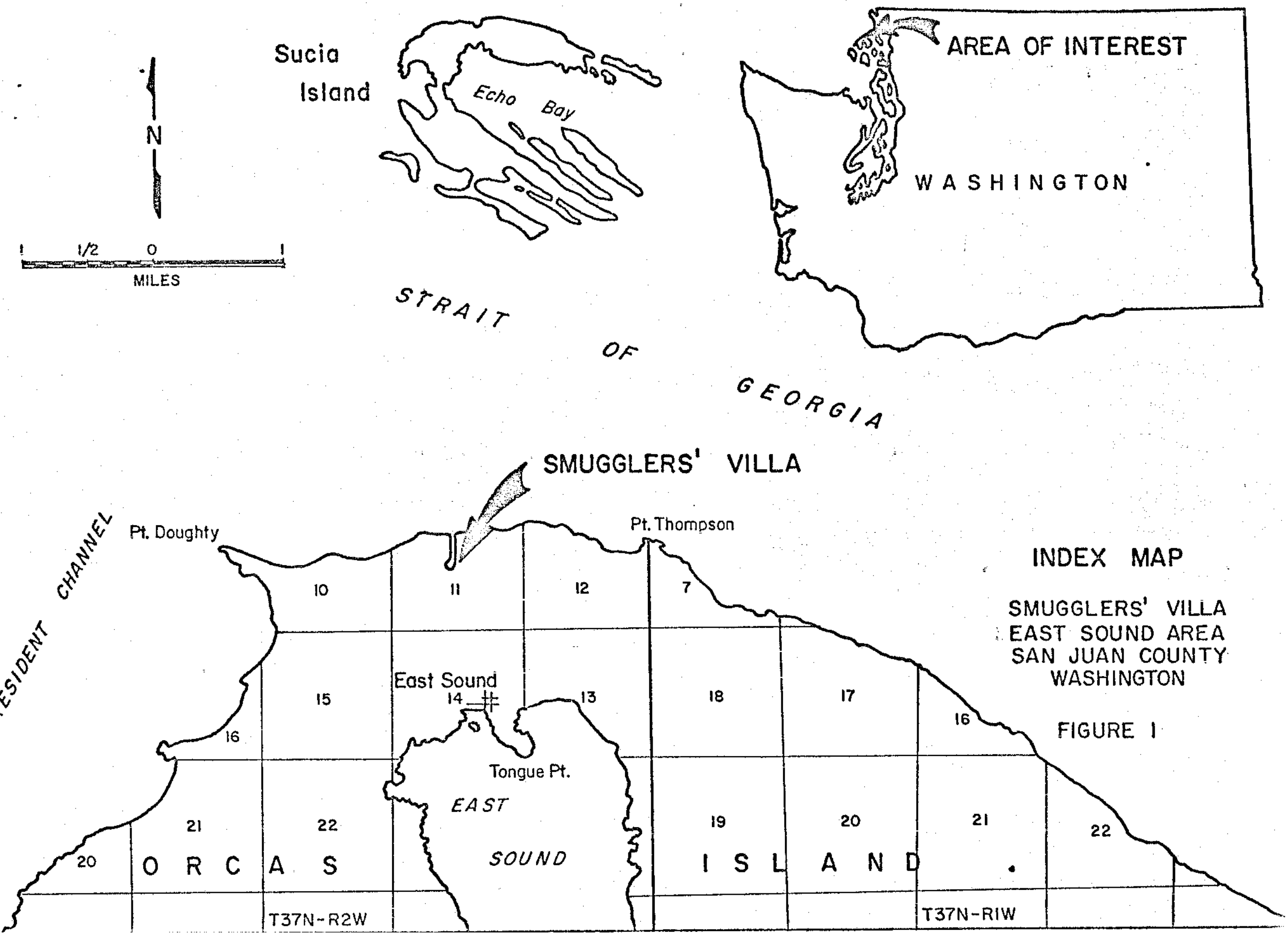

TIDE - FEET BELOW M.P. (BOAT BASIN DOCK)
TIME IN MINUTES AFTER PUMP OFF
M.P. TO WATER LEVEL IN FEET (M.P. = 1.4 FEET ABOVE PUMPHOUSE FLOOR)
A
B
C
D
E
F
TIME - RECOVERY GRAPH
WITH TIDAL CHART
OBSERVATION WELL
SMUGGLERS' VILLA
ORCAS ISLAND
SAN JUAN COUNTY, WA.
TEST OF NOV. 30, DEC. 1, 1972
x - RECOVERY
⊙ - TIDE LEVEL

FIGURE 4



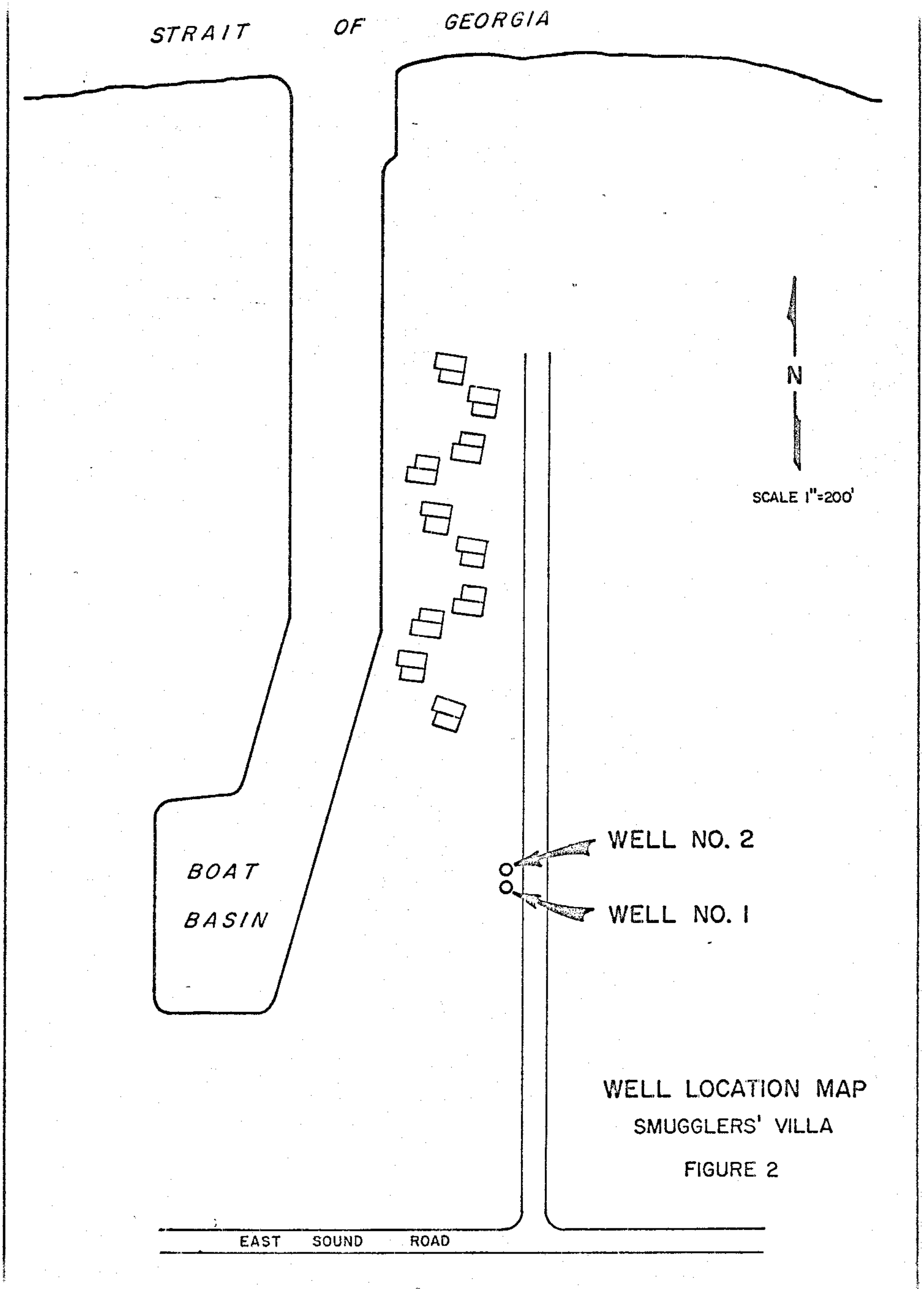
DRAWDOWN - DISTANCE - TIME CURVES
SMUGGLERS' VILLA
ORCAS ISLAND
S = .05
Q = 11 g.p.m.
T = 3000 g.p.d/ft.
FIGURE 5
1 DAY
10 DAYS
100 DAYS
1000 DAYS
DISTANCE FROM PUMPED WELL IN FEET
DRAWDOWN IN FEET
1,000
100
10
0
1
2
3
4
5
6
7



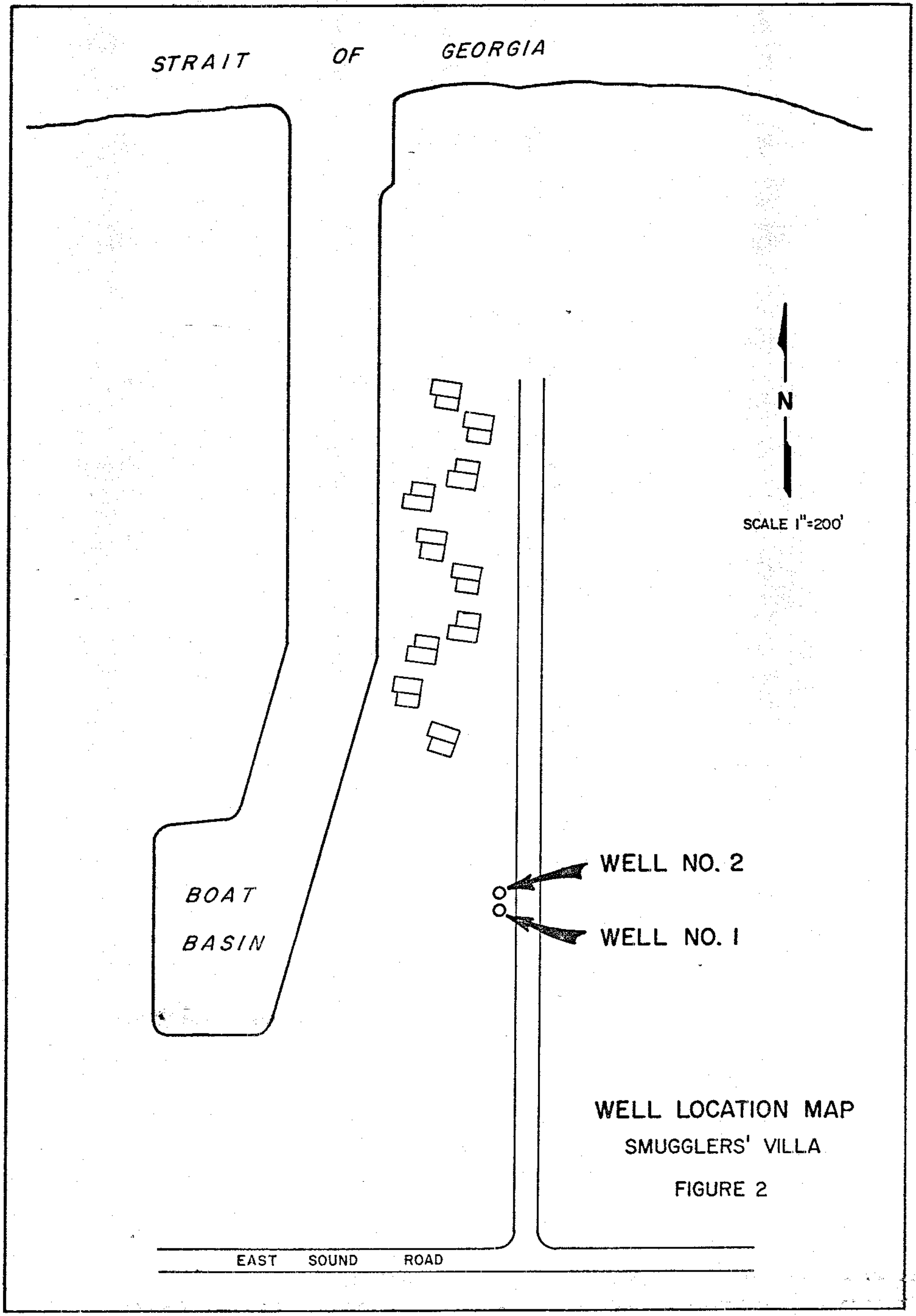
INDEX MAP

SMUGGLERS' VILLA
EAST SOUND AREA
SAN JUAN COUNTY
WASHINGTON

FIGURE 1



WELL LOCATION MAP
SMUGGLERS' VILLA
FIGURE 2



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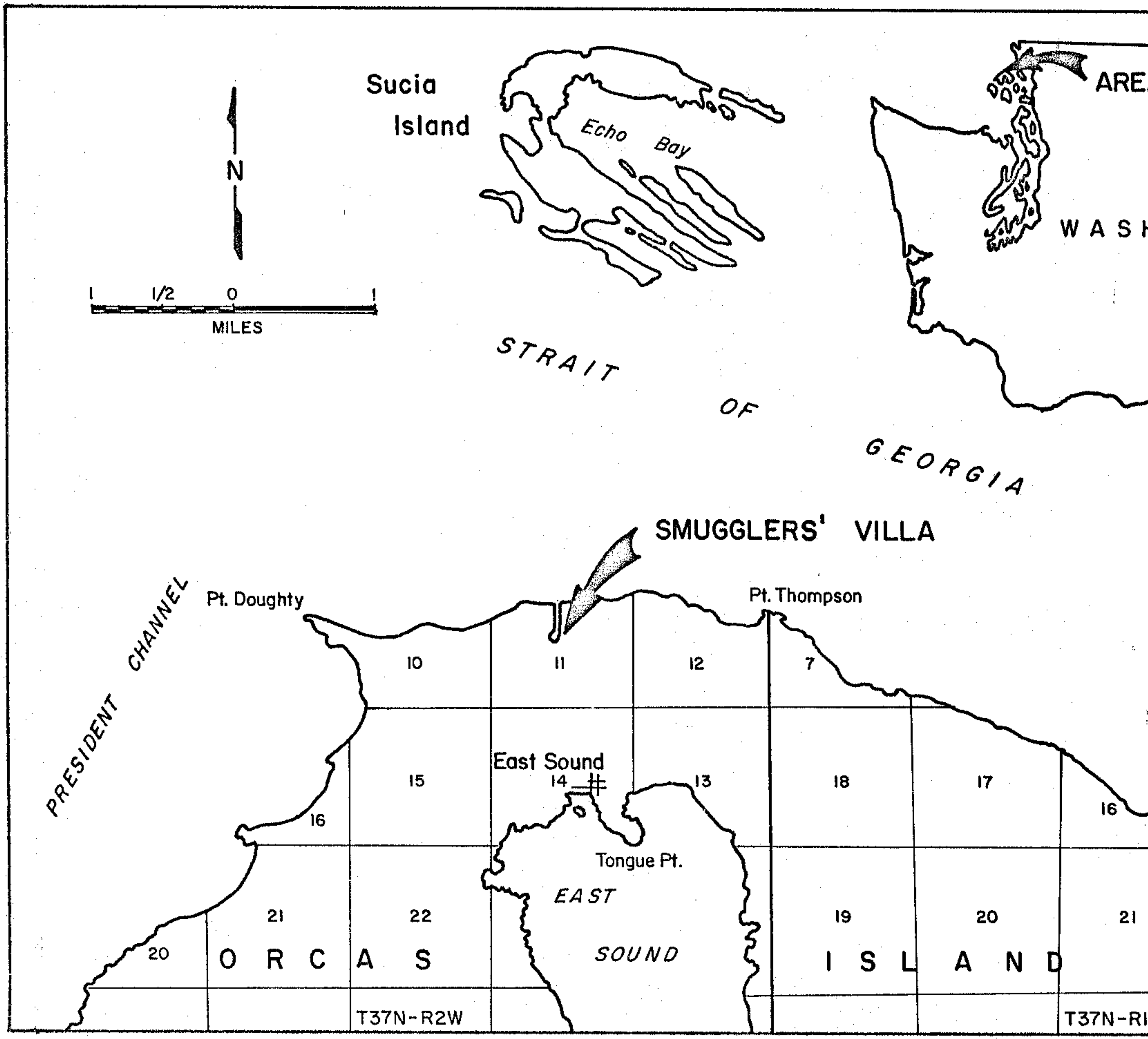
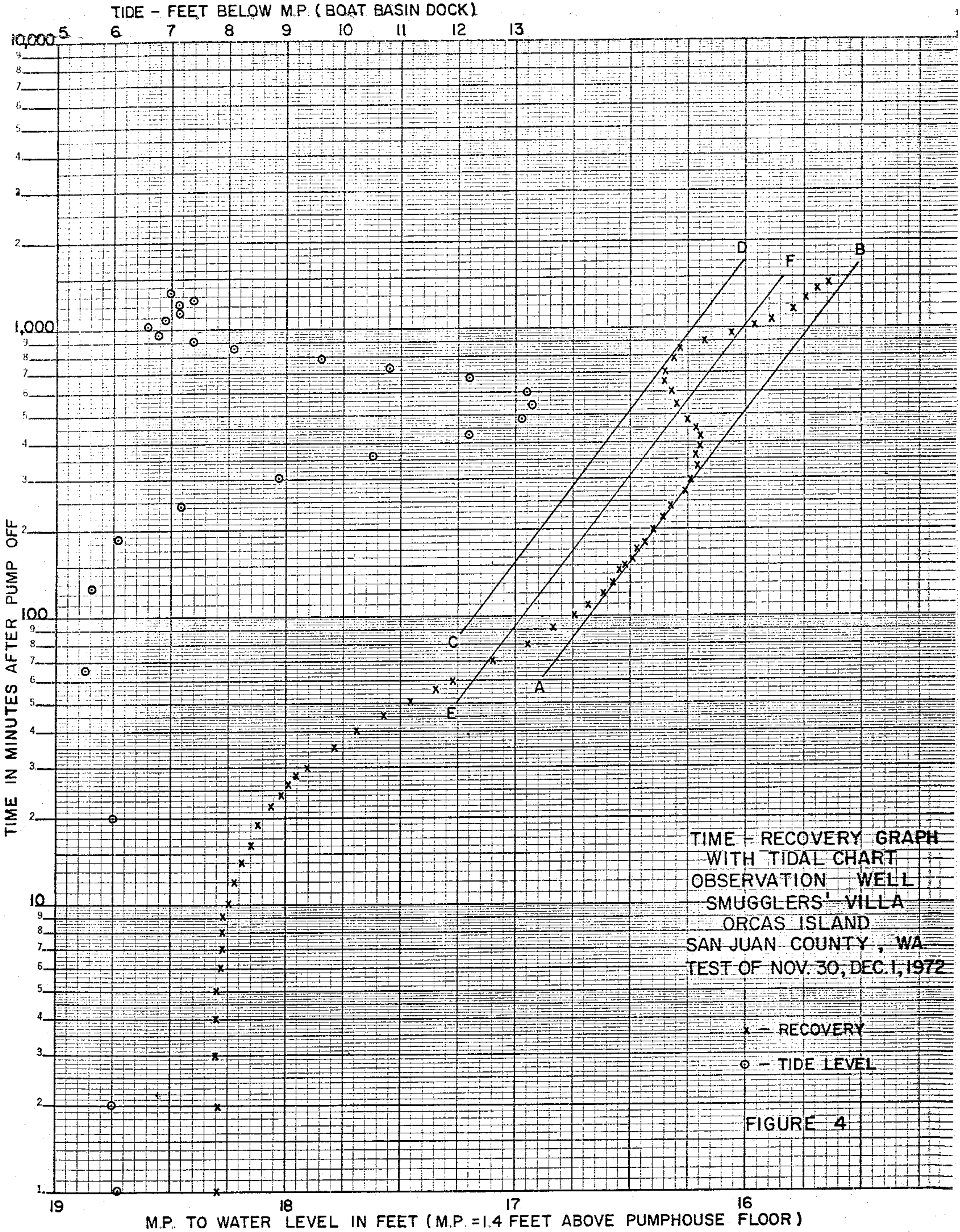
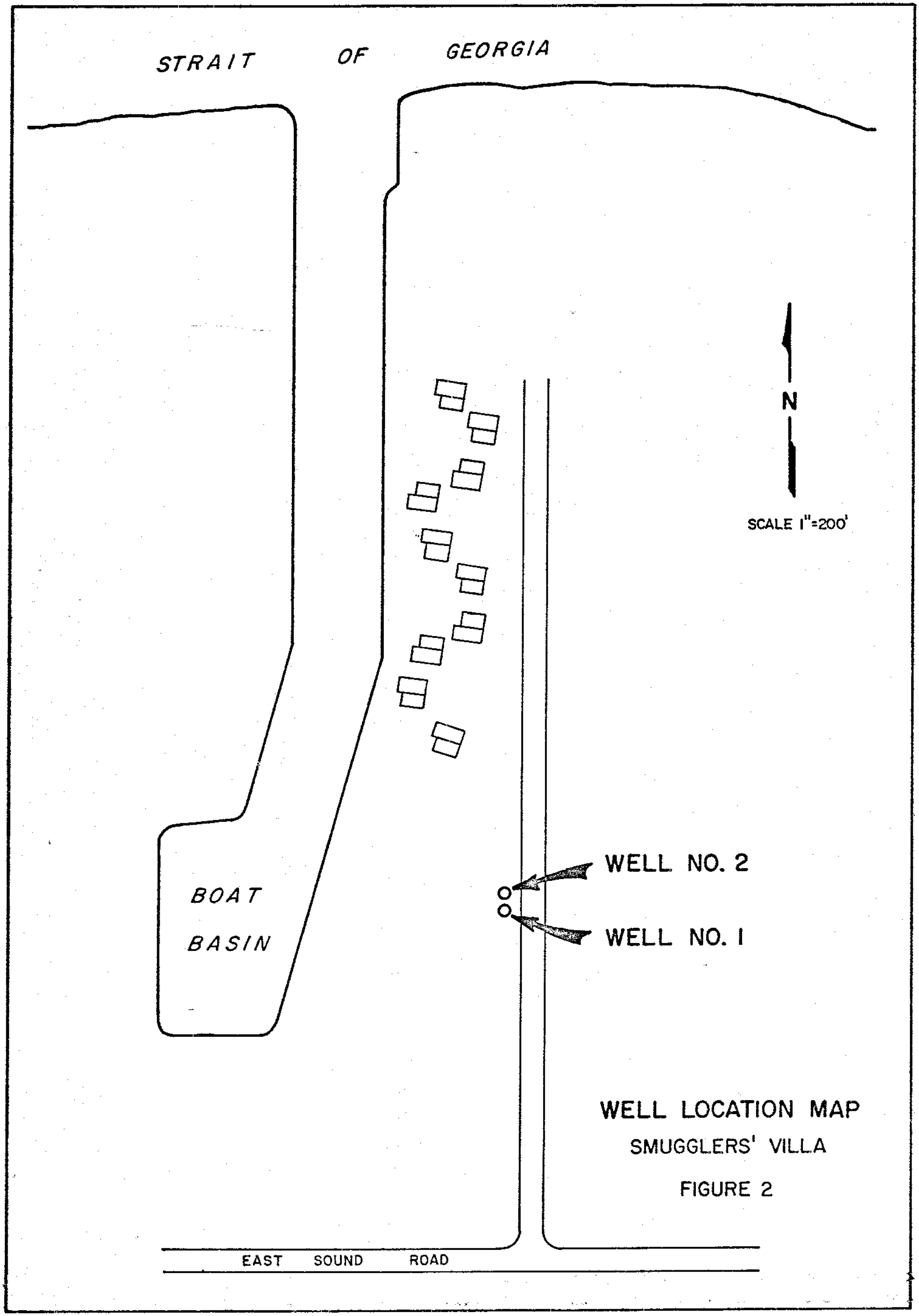


INDEX MAP

SMUGGLERS' VILLA
EAST SOUND AREA
SAN JUAN COUNTY
WASHINGTON

FIGURE 1


TIDE - FEET BELOW M.P. (BOAT BASIN DOCK)
5 6 7 8 9 10 11 12 13
TIME IN MINUTES AFTER PUMP OFF
10,000
1,000
100
10
1.
19 18 17 16
M.P. TO WATER LEVEL IN FEET (M.P. = 1.4 FEET ABOVE PUMPHOUSE FLOOR)
A
B
C
D
E
F
TIME - RECOVERY GRAPH
WITH TIDAL CHART
OBSERVATION WELL
SMUGGLERS' VILLA
ORCAS ISLAND
SAN JUAN COUNTY, WA
TEST OF NOV. 30, DEC. 1, 1972
x - RECOVERY
⊙ - TIDE LEVEL
FIGURE 4



WELL LOCATION MAP
SMUGGLERS' VILLA
FIGURE 2

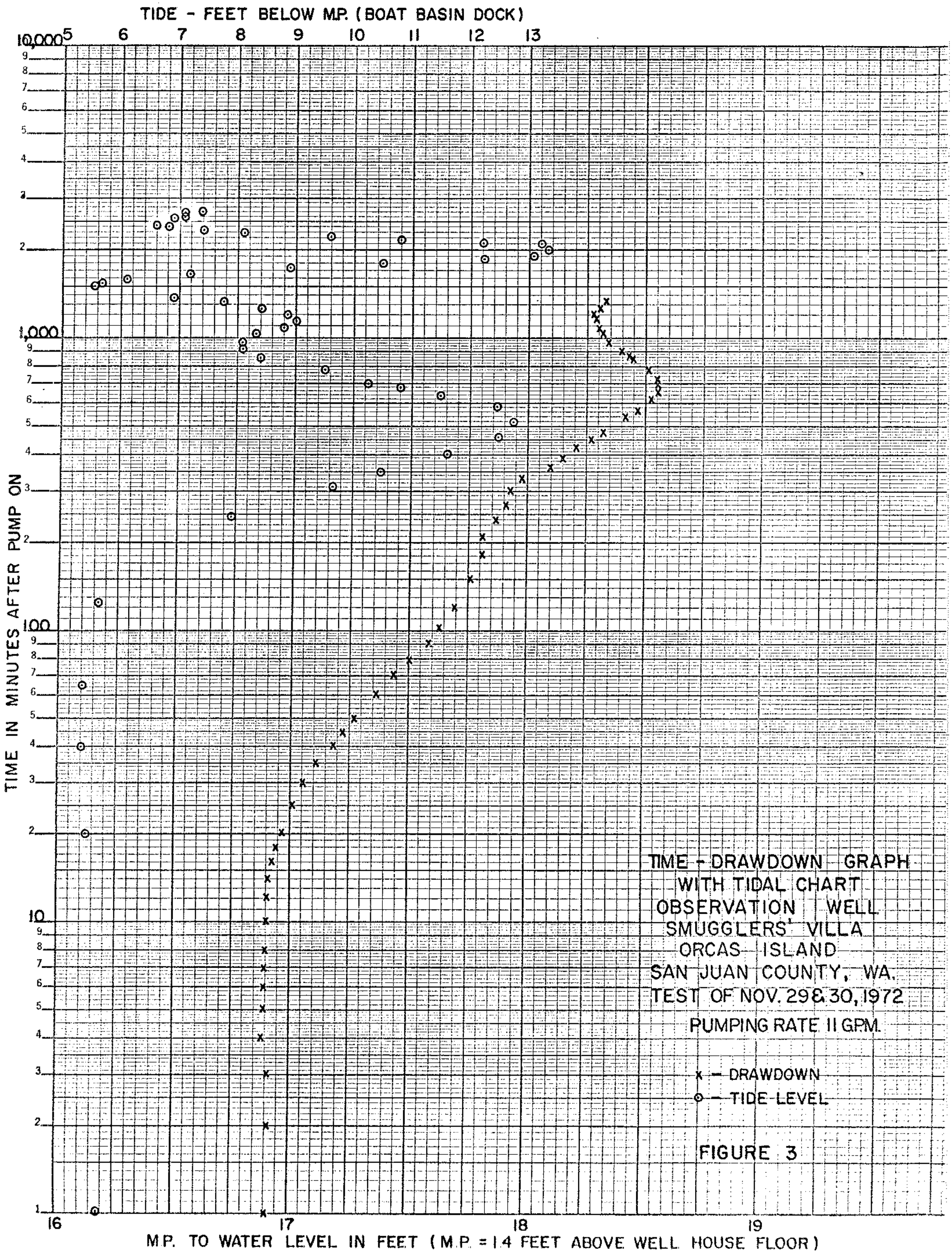
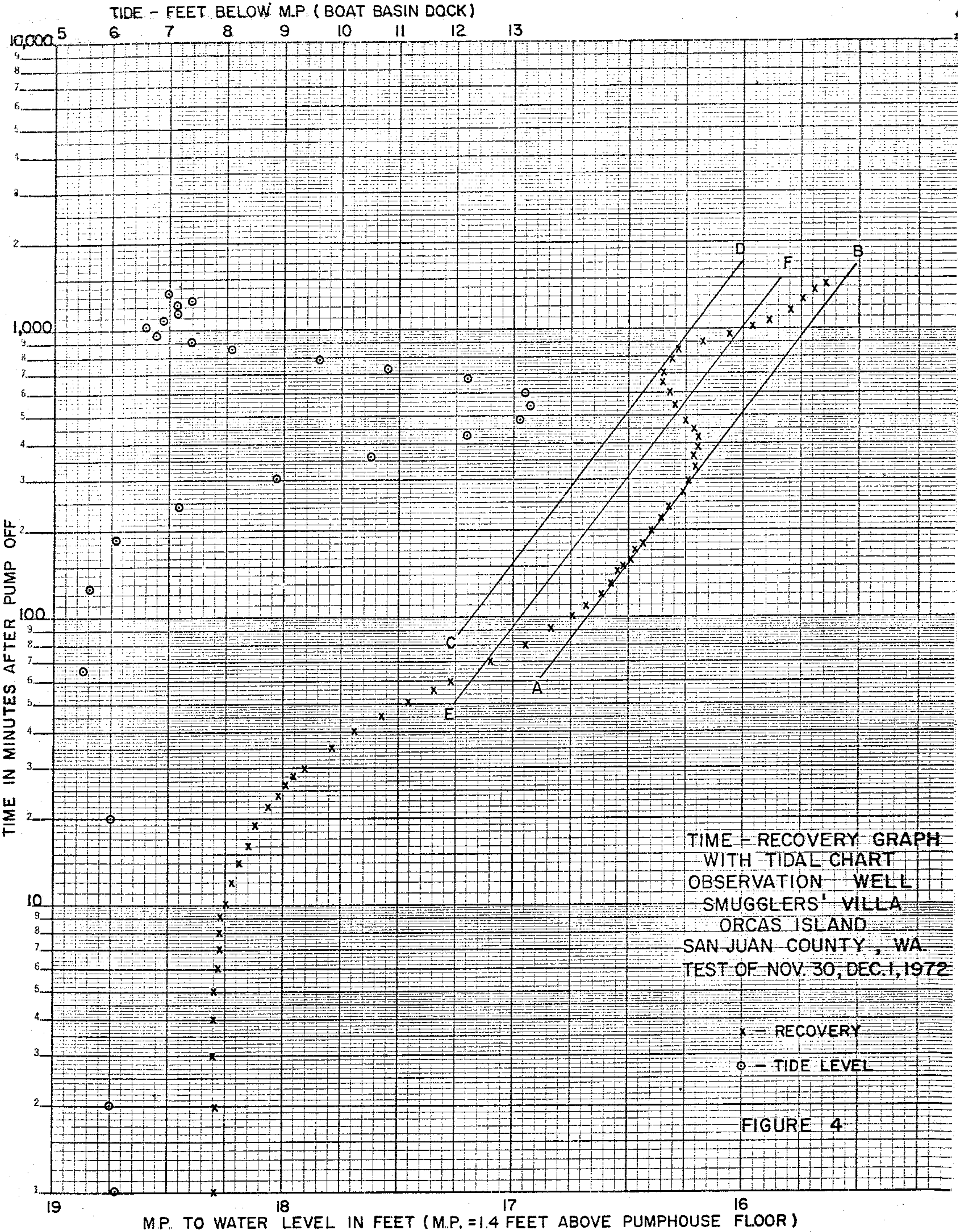

TIDE - FEET BELOW M.P. (BOAT BASIN DOCK)
5 6 7 8 9 10 11 12 13
TIME IN MINUTES AFTER PUMP ON
10,000
1,000
100
10
1
16 17 18 19
M.P. TO WATER LEVEL IN FEET (M.P. = 1.4 FEET ABOVE WELL HOUSE FLOOR)
TIME - DRAWDOWN GRAPH
WITH TIDAL CHART
OBSERVATION WELL
SMUGGLERS' VILLA
ORCAS ISLAND
SAN JUAN COUNTY, WA.
TEST OF NOV. 29 & 30, 1972
PUMPING RATE 11 G.P.M.
x - DRAWDOWN
⊙ - TIDE LEVEL

FIGURE 3


TIDE - FEET BELOW M.P. (BOAT BASIN DOCK)
5
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9
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11
12
13
10,000
1,000
100
10
1
TIME IN MINUTES AFTER PUMP OFF
D
F
B
C
E
A
19
18
17
16
M.P. TO WATER LEVEL IN FEET (M.P. =1.4 FEET ABOVE PUMPHOUSE FLOOR)
TIME - RECOVERY GRAPH
WITH TIDAL CHART
OBSERVATION WELL
SMUGGLERS' VILLA
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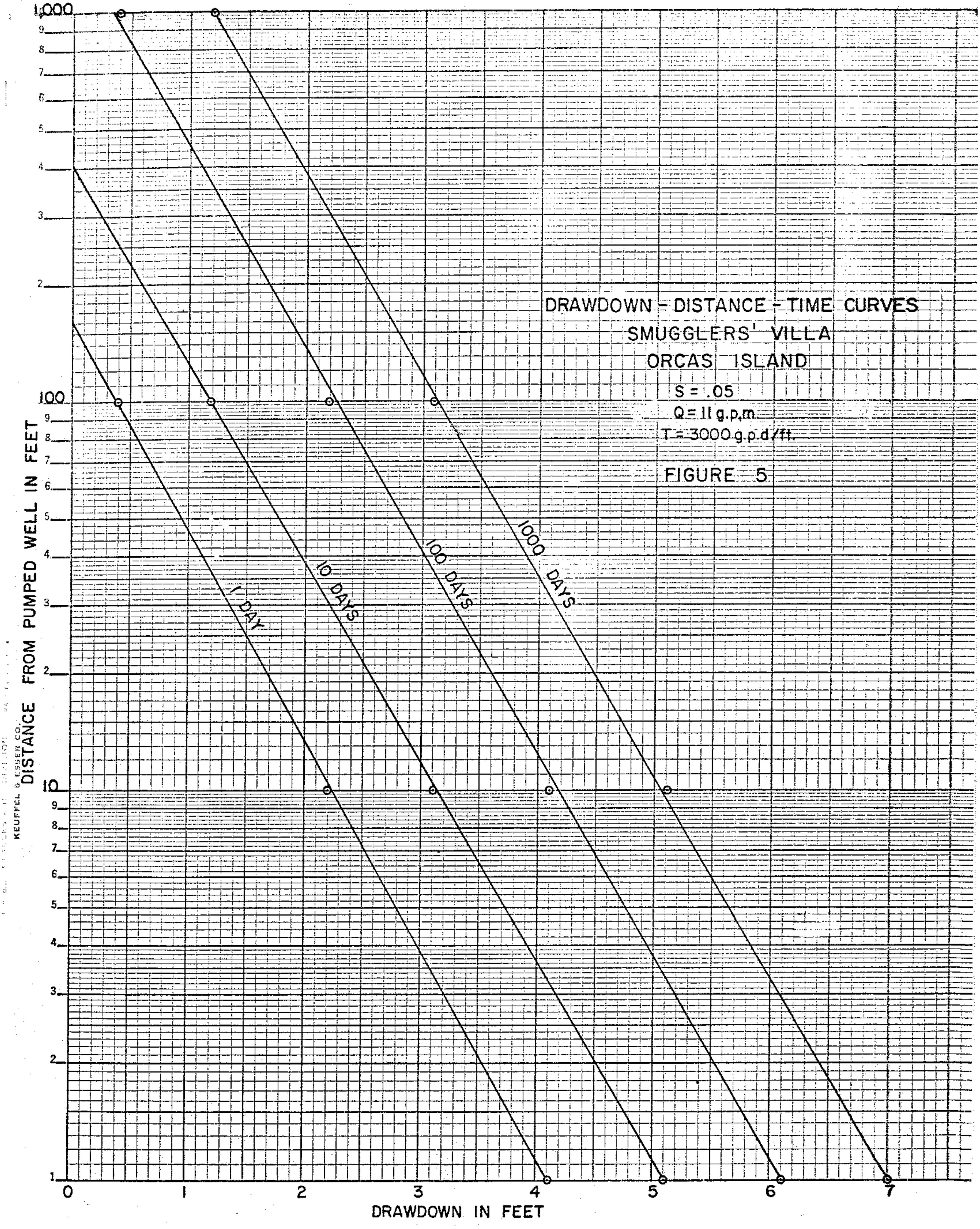
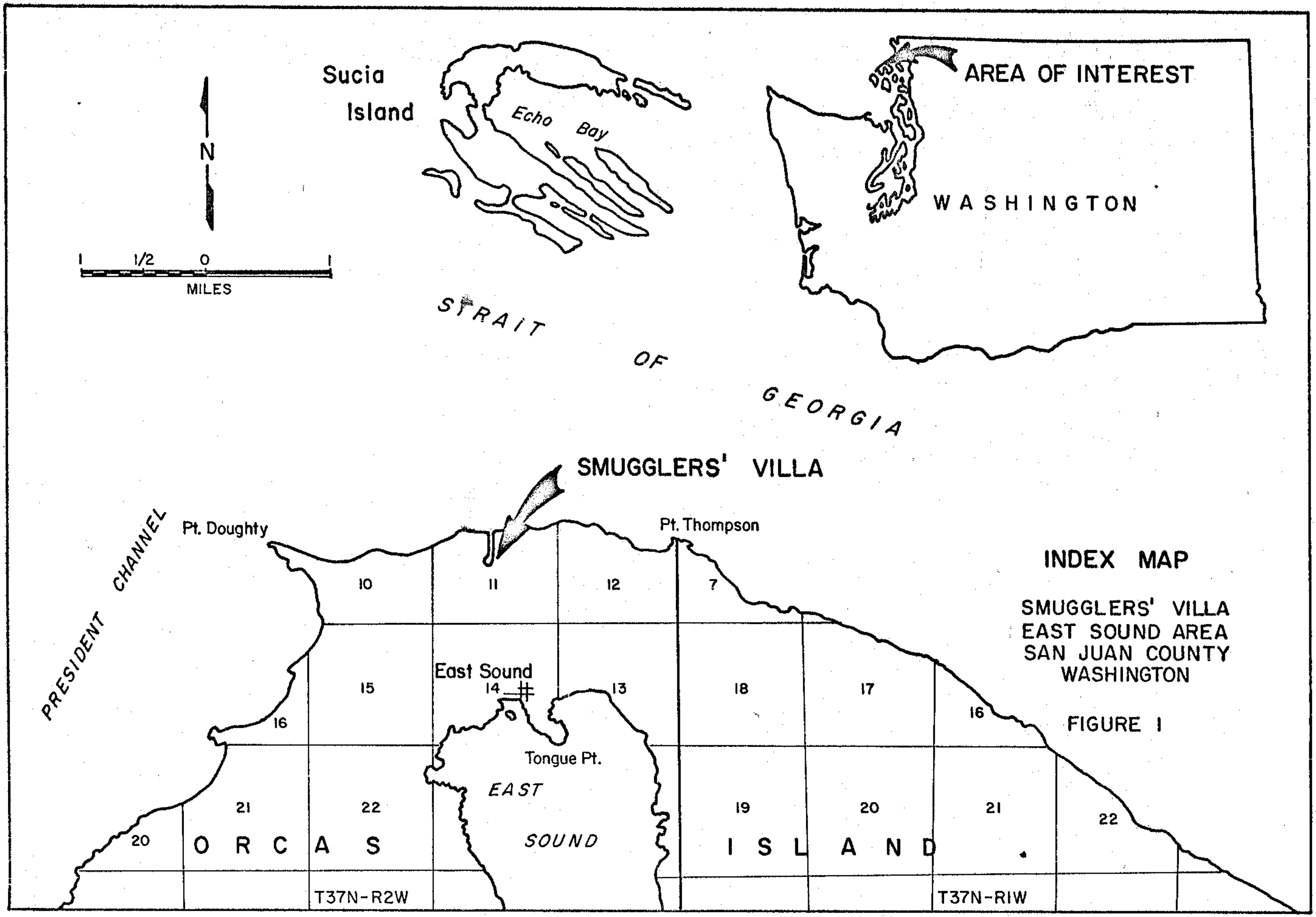
x — RECOVERY
⊙ — TIDE LEVEL
FIGURE 4



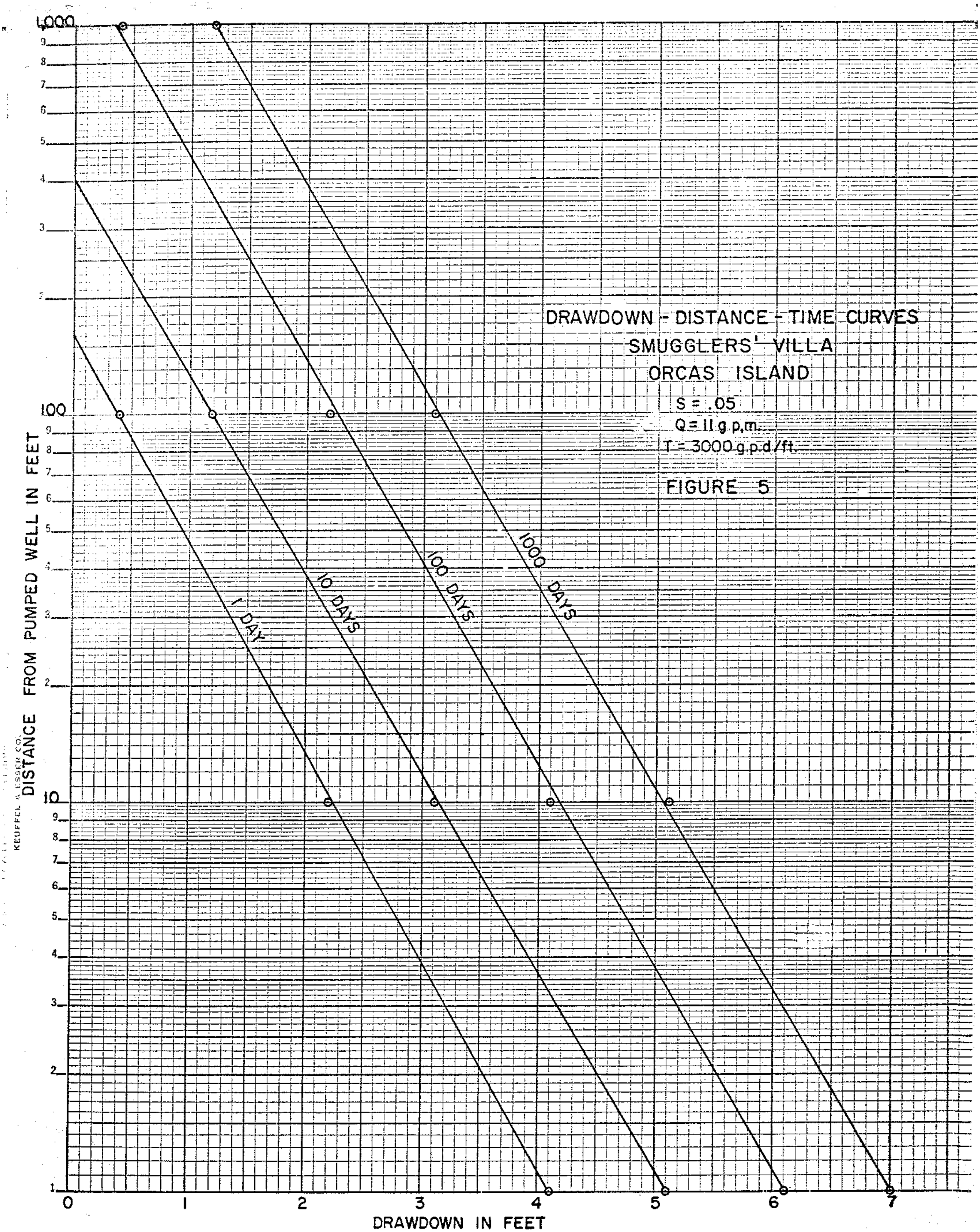
DRAWDOWN - DISTANCE - TIME CURVES
SMUGGLERS' VILLA
ORCAS ISLAND
S = .05
Q = 11 g.p.m.
T = 3000 g.p.d./ft.
FIGURE 5
1 DAY
10 DAYS
100 DAYS
1000 DAYS
DISTANCE FROM PUMPED WELL IN FEET
DRAWDOWN IN FEET
KEUFFEL & ESSER CO.



INDEX MAP

SMUGGLERS' VILLA
EAST SOUND AREA
SAN JUAN COUNTY
WASHINGTON

FIGURE 1


DRAWDOWN - DISTANCE - TIME CURVES
SMUGGLERS' VILLA
ORCAS ISLAND
S = .05
Q = 11 g.p.m.
T = 3000 g.p.d./ft.
FIGURE 5
1 DAY
10 DAYS
100 DAYS
1000 DAYS
DISTANCE FROM PUMPED WELL IN FEET
DRAWDOWN IN FEET
1,000
100
10
1
0
1
2
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7
KEUFFEL & ESSER CO.

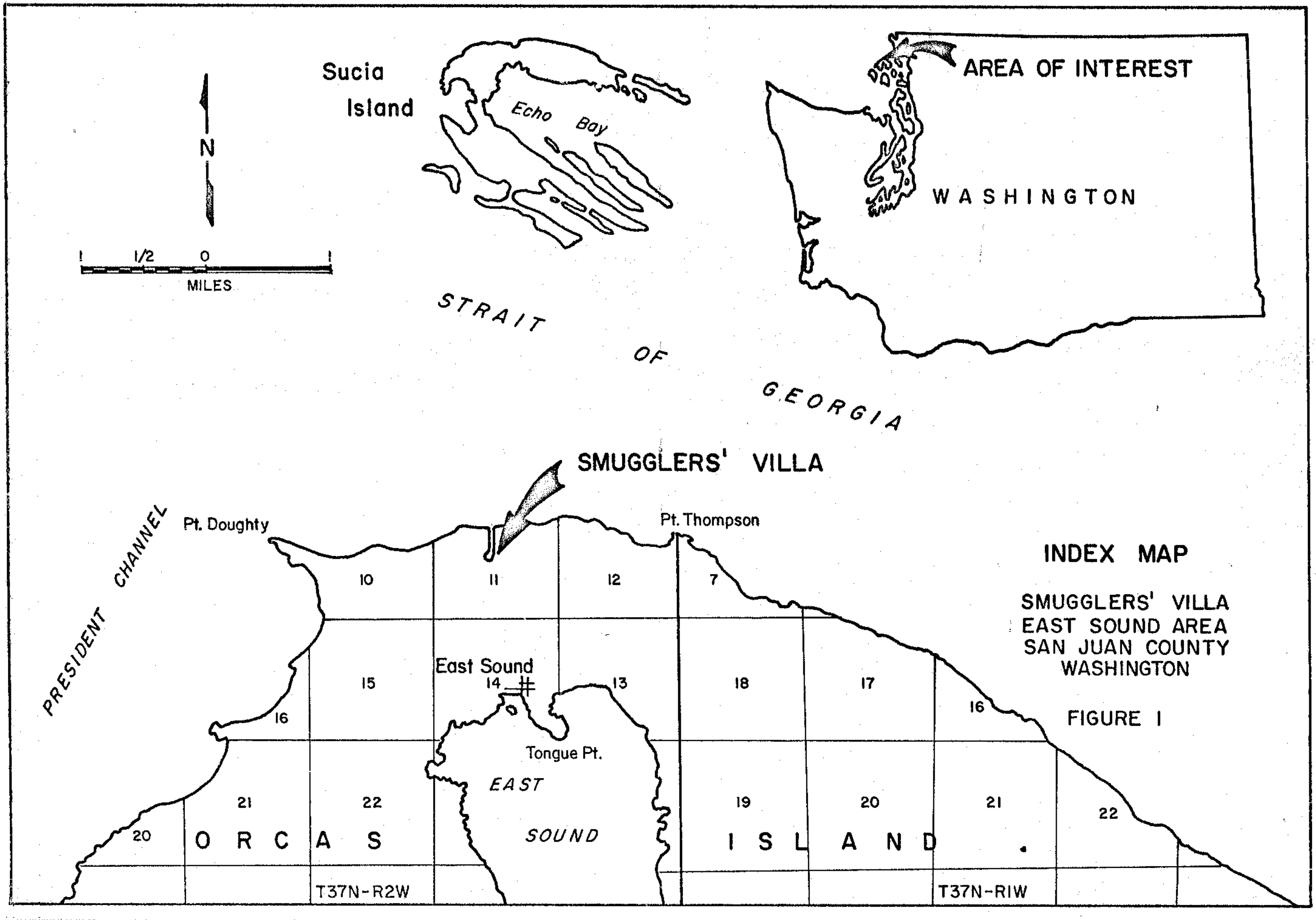

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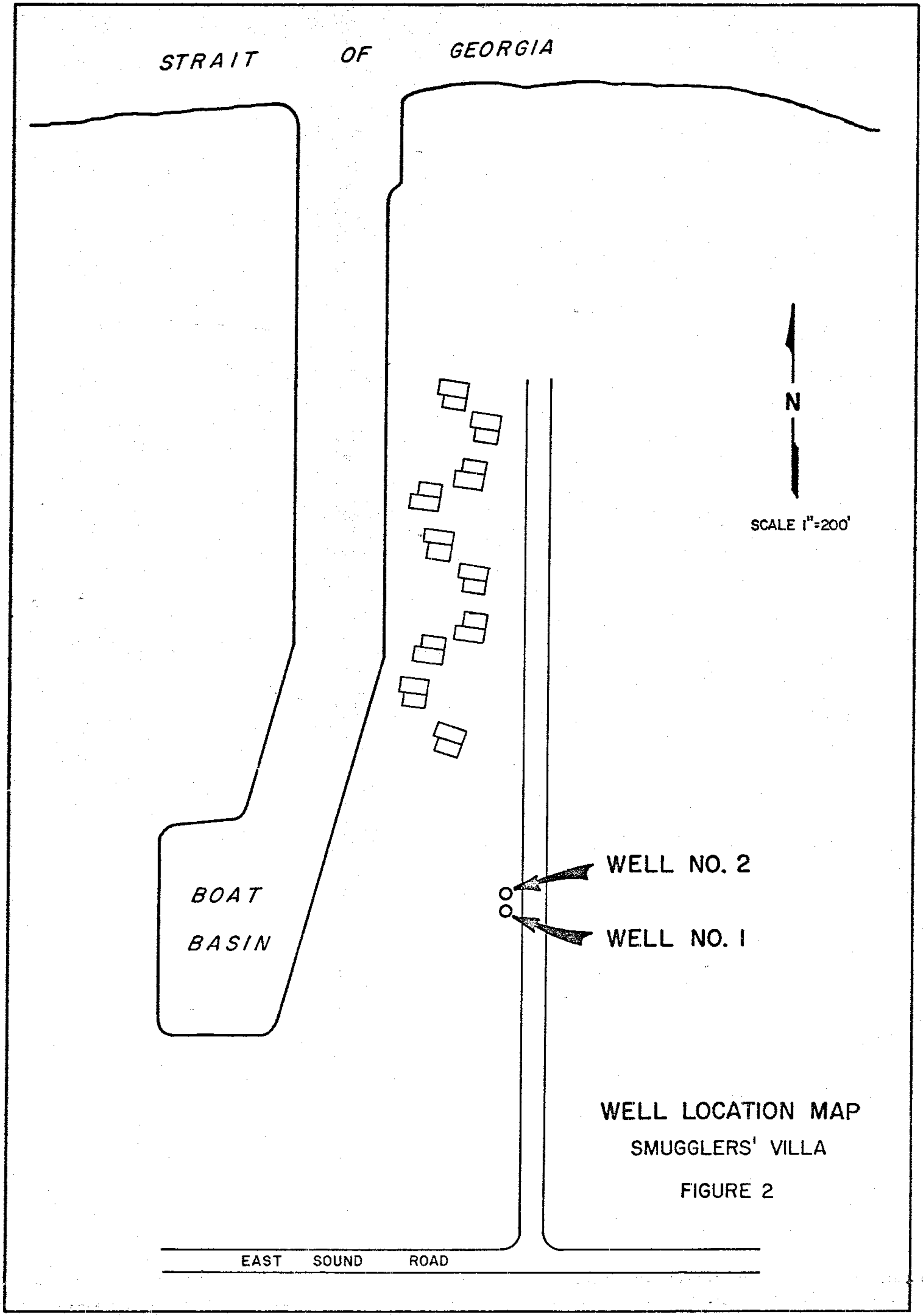
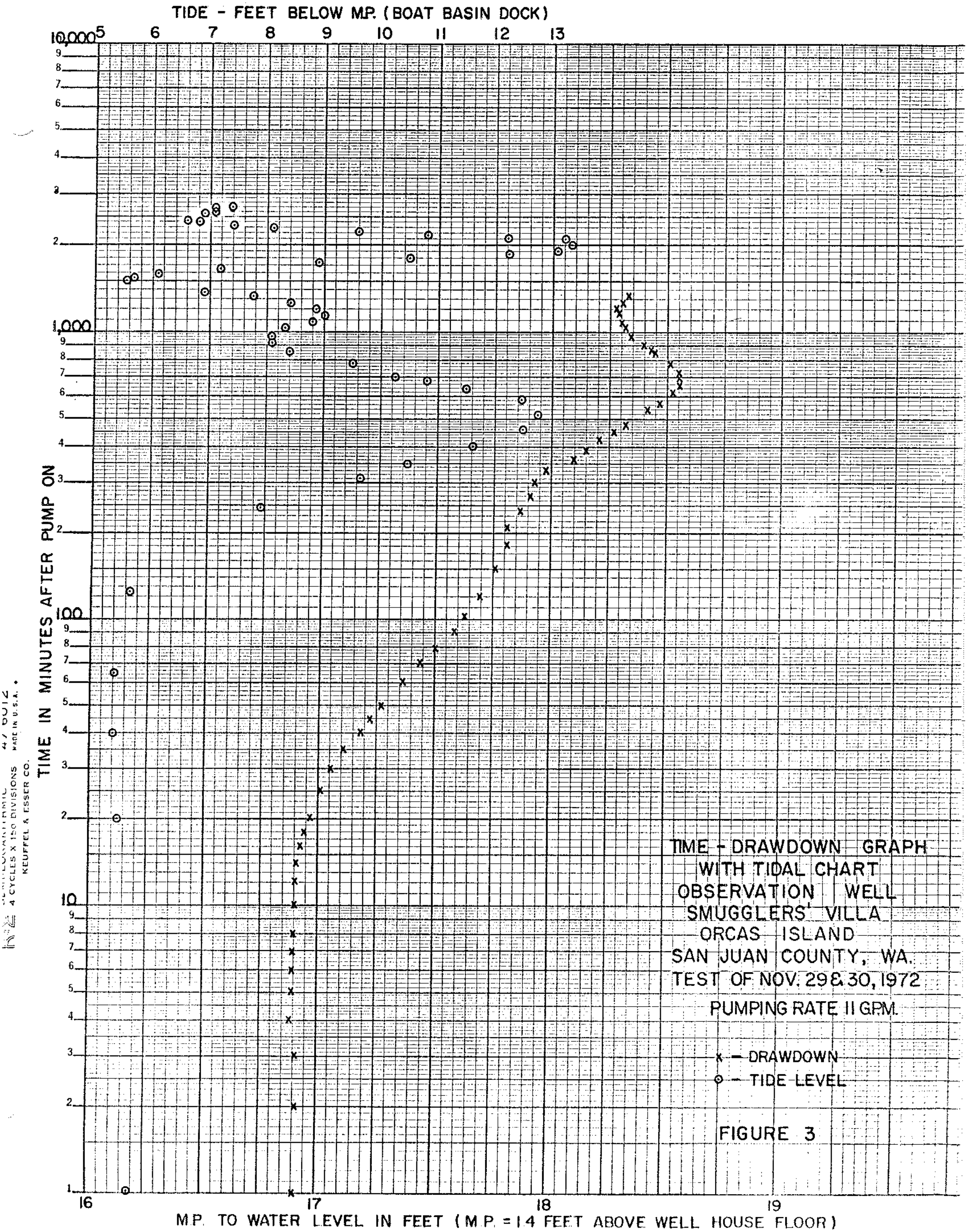
FIGURE 1



WELL LOCATION MAP
SMUGGLERS' VILLA
FIGURE 2



TIDE - FEET BELOW M.P. (BOAT BASIN DOCK)
5
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9
10
11
12
13
10,000
1,000
100
10
1
TIME IN MINUTES AFTER PUMP ON
16
17
18
19
M.P. TO WATER LEVEL IN FEET (M.P. = 1.4 FEET ABOVE WELL HOUSE FLOOR)
TIME - DRAWDOWN GRAPH
WITH TIDAL CHART
OBSERVATION WELL
SMUGGLERS' VILLA
ORCAS ISLAND
SAN JUAN COUNTY, WA.
TEST OF NOV. 29 & 30, 1972
PUMPING RATE 11 GPM.
x — DRAWDOWN
⊙ — TIDE LEVEL
4 CYCLES X 150 DIVISIONS
KEUFFEL & ESSER CO.
MADE IN U.S.A.

FIGURE 3