2
4
11
(8)

Mobil stations with DOS equivale
(see inside

ESTABLISH GEODETIC CONTROL POINTS, SIERRA LEONE FOR MOBIL EXPLORATION AND PRODUCING SERVICES, INC., DALLAS, TEXAS

Published by NCS International, Inc.
October, 1980

TABLE OF CONTENTS

SECTION I

PROJECT RECORD

PROJECT RECORD

Operator(s)	:	Mr. Graham Jackson Mr. Phil Thompson
Client	:	Mobil Exploration & Producing Services Dallas, Texas. U.S.A.
Local Contact	:	Mr. Alfred Amoah Vice-President Mobil Exploration & Producing Services Freetown, Sierra Leone, West Africa
Area	:	Sierra Leone, West Africa
Project Name/No.	:	Mobil, Sierra Leone/210

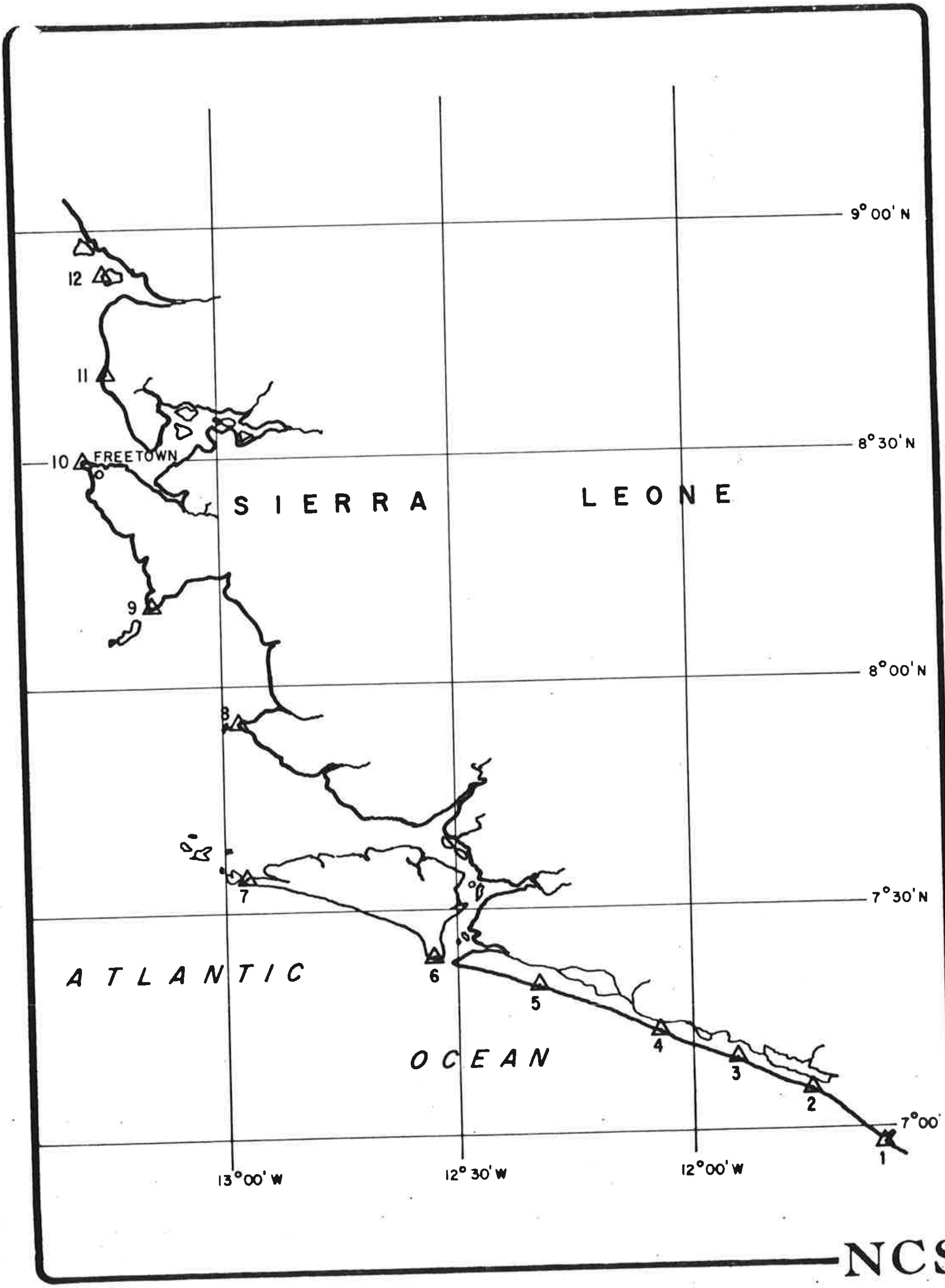
Project team leaves London	:	05/16/80
Project team returns London	:	08/03/80
System begins field operation	:	05/23/80
System completes field operation	:	07/28/80

General Project Description :

Establishment of a network of geodetic control points suitable as base stations for offshore navigation in Sierra Leone waters. Collected satellite data to be GEODOP processed to maximize consistency and absolute accuracy.

SECTION II

LOCATION MAP


9°00'N
8°30'N
8°00'N
7°30'N
7°00'
13°00'W
12°30'W
12°00'W
FREETOWN
SIERRA LEONE
ATLANTIC OCEAN
1
2
3
4
5
6
7
8
9
10
11
12

NCS

SECTION III

FINAL RESULTS

FINAL RESULTS

GEODOP processing of satellite data with vertical offsets reduced to monument level.

Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator

Station Name	:	Mano Salija
Number	:	1
Latitude	:	06 Deg 56 Min 29.052 Sec N
Longitude	:	11 Deg 31 Min 43.149 Sec W
Height	:	38.60 meters
Northing	:	768,016.55 meters
Easting	:	220,584.46 meters
Central Meridian	:	09 degrees W

Station Name	:	Kasi
Number	:	2
Latitude	:	07 Deg 05 Min 21.598 Sec N
Longitude	:	11 Deg 44 Min 39.329 Sec W
Height	:	41.80 meters
Northing	:	784,520.66 meters
Easting	:	196,838.81 meters
Central Meridian	:	09 degrees W

Station Name	:	Bengani
Number	:	3
Latitude	:	07 Deg 09 Min 47.666 Sec N
Longitude	:	11 Deg 53 Min 36.375 Sec W
Height	:	41.80 meters
Northing	:	792,801.35 meters
Easting	:	180,396.76 meters
Central Meridian	:	09 degrees W

Station Name	:	Mano Curanco
Number	:	4
Latitude	:	07 Deg 14 Min 27.381 Sec N
Longitude	:	12 Deg 05 Min 04.331 Sec W
Height	:	42.72 meters
Northing	:	801,417.00 meters
Easting	:	821,983.33 meters
Central Meridian	:	15 degrees W

Station Name	:	Yile
Number	:	5
Latitude	:	07 Deg 19 Min 52.490 Sec N
Longitude	:	12 Deg 19 Min 03.237 Sec W
Height	:	42.12 meters
Northing	:	811,252.32 meters
Easting	:	796,169.07 meters
Central Meridian	:	15 degrees W

Station Name	:	Shebar
Number	:	6
Latitude	:	07 Deg 23 Min 26.048 Sec N
Longitude	:	12 Deg 32 Min 49.968 Sec W
Height	:	41.32 meters
Northing	:	817,670.90 meters
Easting	:	770,761.74 meters
Central Meridian	:	15 degrees W

Station Name	:	Cape St. Ann
Number	:	7
Latitude	:	07 Deg 34 Min 18.527 Sec N
Longitude	:	12 Deg 57 Min 11.831 Sec W
Height	:	40.19 meters
Northing	:	837,493.04 meters
Easting	:	725,821.86 meters
Central Meridian	:	15 degrees W

Station Name	:	Shenge
Number	:	8
Latitude	:	07 Deg 54 Min 59.211 Sec N
Longitude	:	12 Deg 57 Min 38.358 Sec W
Height	:	44.78 meters
Northing	:	875,612.04 meters
Easting	:	724,825.59 meters
Central Meridian	:	15 degrees W

Station Name	:	Cape Shilling
Number	:	9
Latitude	:	08 Deg 10 Min 25.329 Sec N
Longitude	:	13 Deg 09 Min 51.182 Sec W
Height	:	48.09 meters
Northing	:	903,961.56 meters
Easting	:	702,248.59 meters
Central Meridian	:	15 degrees W

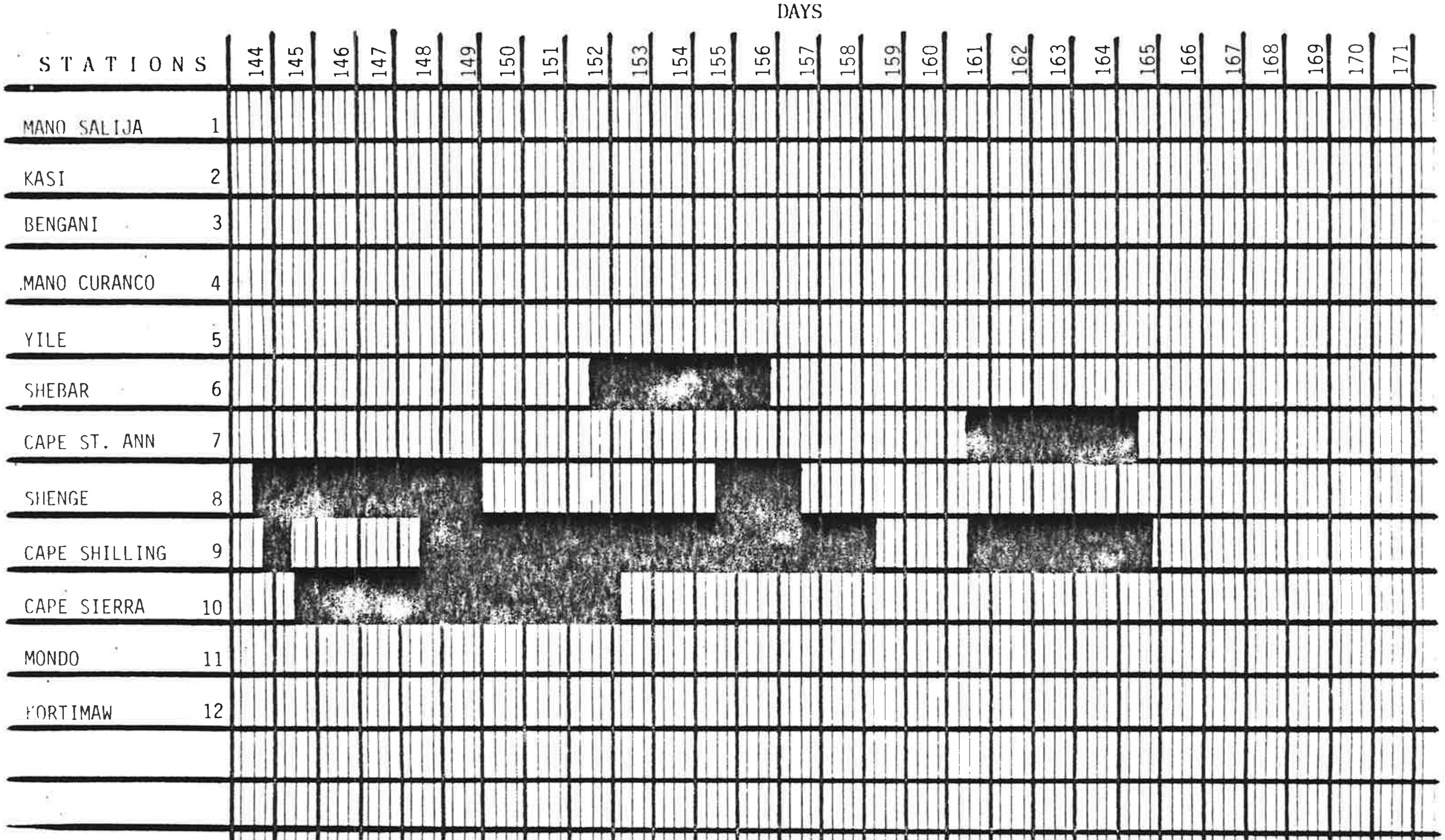
Station Name	:	Cape Sierra
Number	:	10
Latitude	:	08 Deg 29 Min 45.145 Sec N
Longitude	:	13 Deg 17 Min 48.561 Sec W
Height	:	57.88 meters
Northing	:	939,529.65 meters
Easting	:	687,481.53 meters
Central Meridian	:	15 degrees W

Station Name	:	Mondo
Number	:	11
Latitude	:	08 Deg 40 Min 45.962 Sec N
Longitude	:	13 Deg 14 Min 39.432 Sec W
Height	:	61.30 meters
Northing	:	959,858.08 meters
Easting	:	693,173.33 meters
Central Meridian	:	15 degrees W

Station Name	:	Korimaw
Number	:	12
Latitude	:	08 Deg 54 Min 16.577 Sec N
Longitude	:	13 Deg 14 Min 20.811 Sec W
Height	:	39.36 meters
Northing	:	984,765.99 meters
Easting	:	693,625.58 meters
Central Meridian	:	15 degrees W

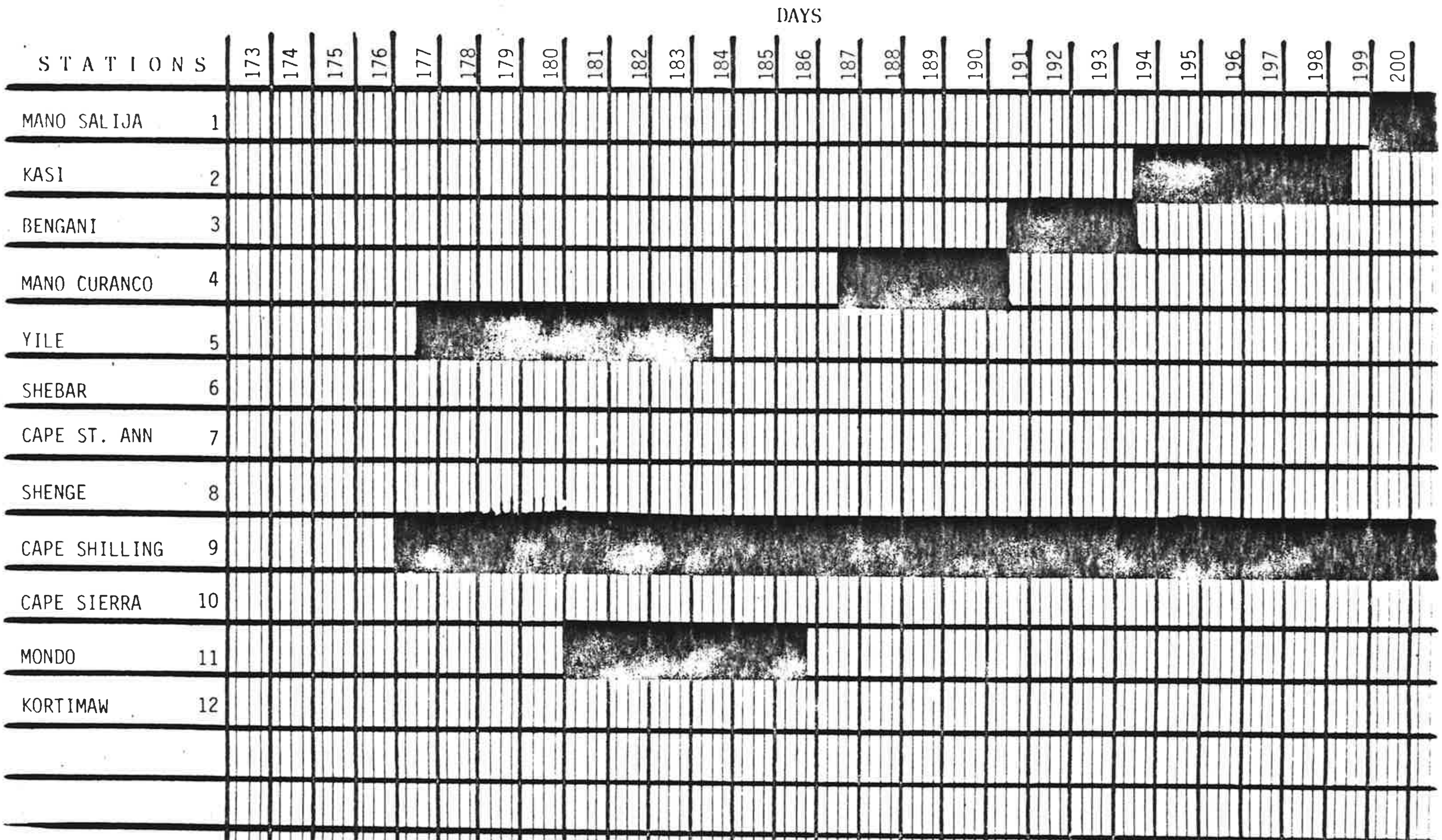
MONTH: MAY/JUNE YEAR: 1980

SCHEDULES: MOBIL OIL - SIERRA LEONE



MONTH: JUNE/JULY YEAR: 1980

SCHEDULES: MOBIL OIL, SIERRA LEONE



MONTH: JULY YEAR: 1980

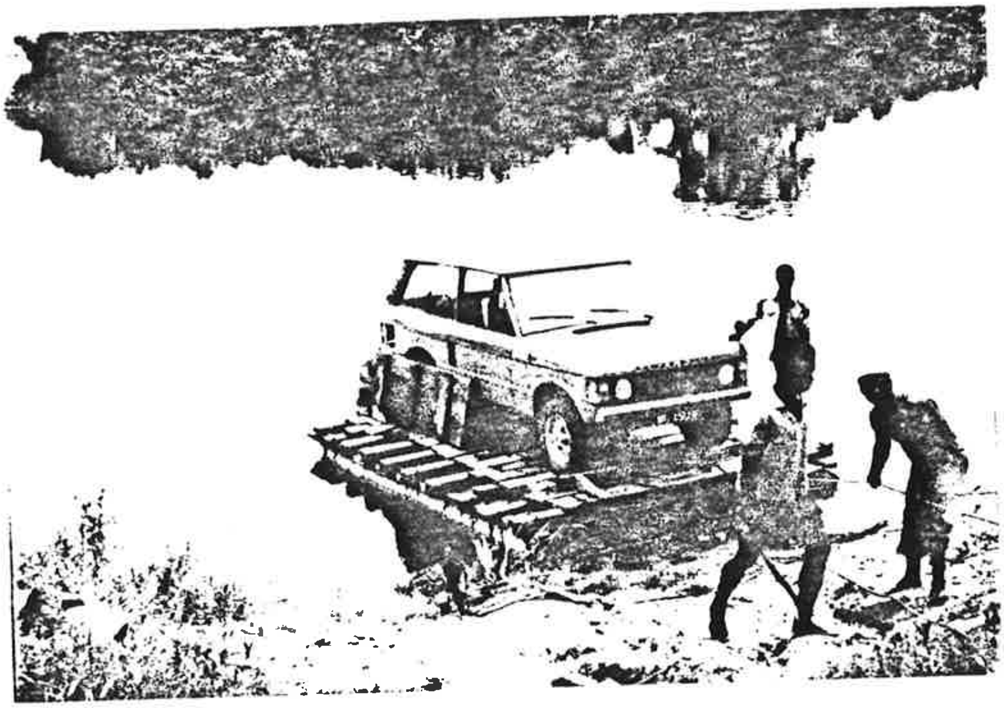
SCHEDULES: MOBIL OIL, SIERRA LEONE

DAYS

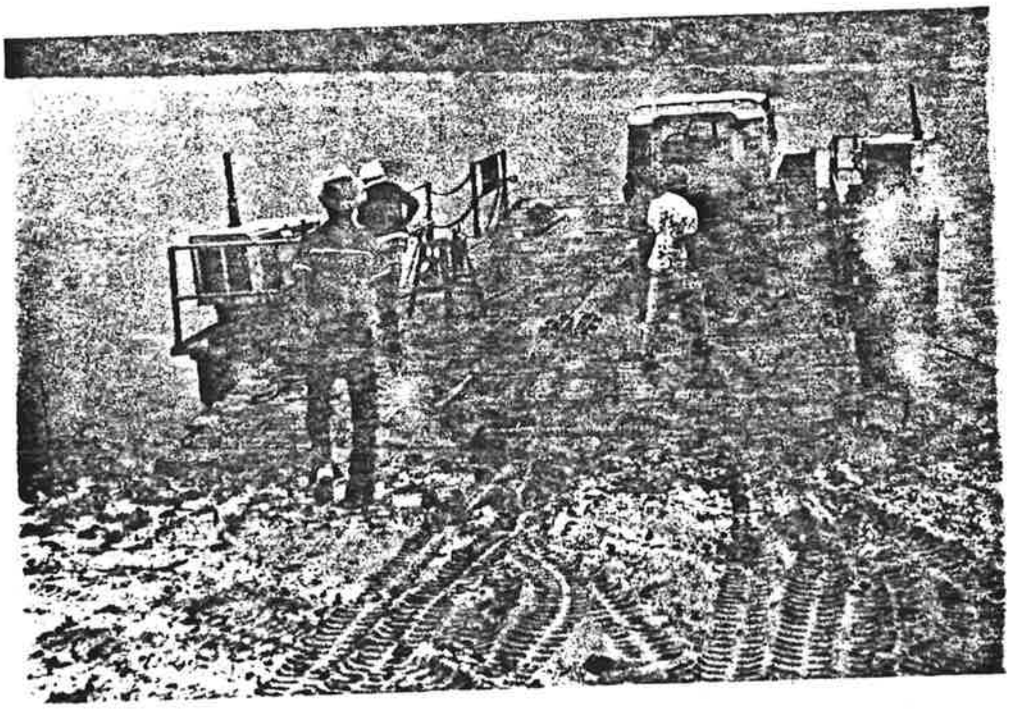
STATIONS		202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229
MANO SALIJA	1																												
KASI	2																												
BENGANI	3																												
MANO CURANCO	4																												
YILE	5																												
SHEBAR	6																												
CAPE ST. ANN	7																												
SHENGE	8																												
CAPE SHILLING	9																												
CAPE SIERRA	10																												
MONDO	11																												
KORTIMAW	12																												

SECTION IV

STATION INFORMATION



FERRIES



STATION INFORMATION

Station Name	:	Mano Salija
Station Number	:	1
Dates Occupied (Mo/Day/Yr)	:	07/17/80 to 07/25/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.20 Meters
Station Latitude	:	06 Deg 56 Min 29.052 Sec N
Longitude	:	11 Deg 31 Min 43.149 Sec W
Height	:	38.60 meters
Northing	:	768,016.55 meters
Easting	:	220,584.46 meters
Antenna Latitude	:	06 Deg 56 Min 29.052 Sec N
Longitude	:	11 Deg 31 Min 43.149 Sec W
Height	:	39.80 meters
Northing	:	768,016.55 meters
Easting	:	220,584.46 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	09 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

At the very boundry between Sierra Leone and Liberia on a sand spit at the mouth of the River Mano.

Location :

Six miles southeast of Sulima and about one mile from Mano Sulija on the Sierra Leone boundry with Liberia.

Access :

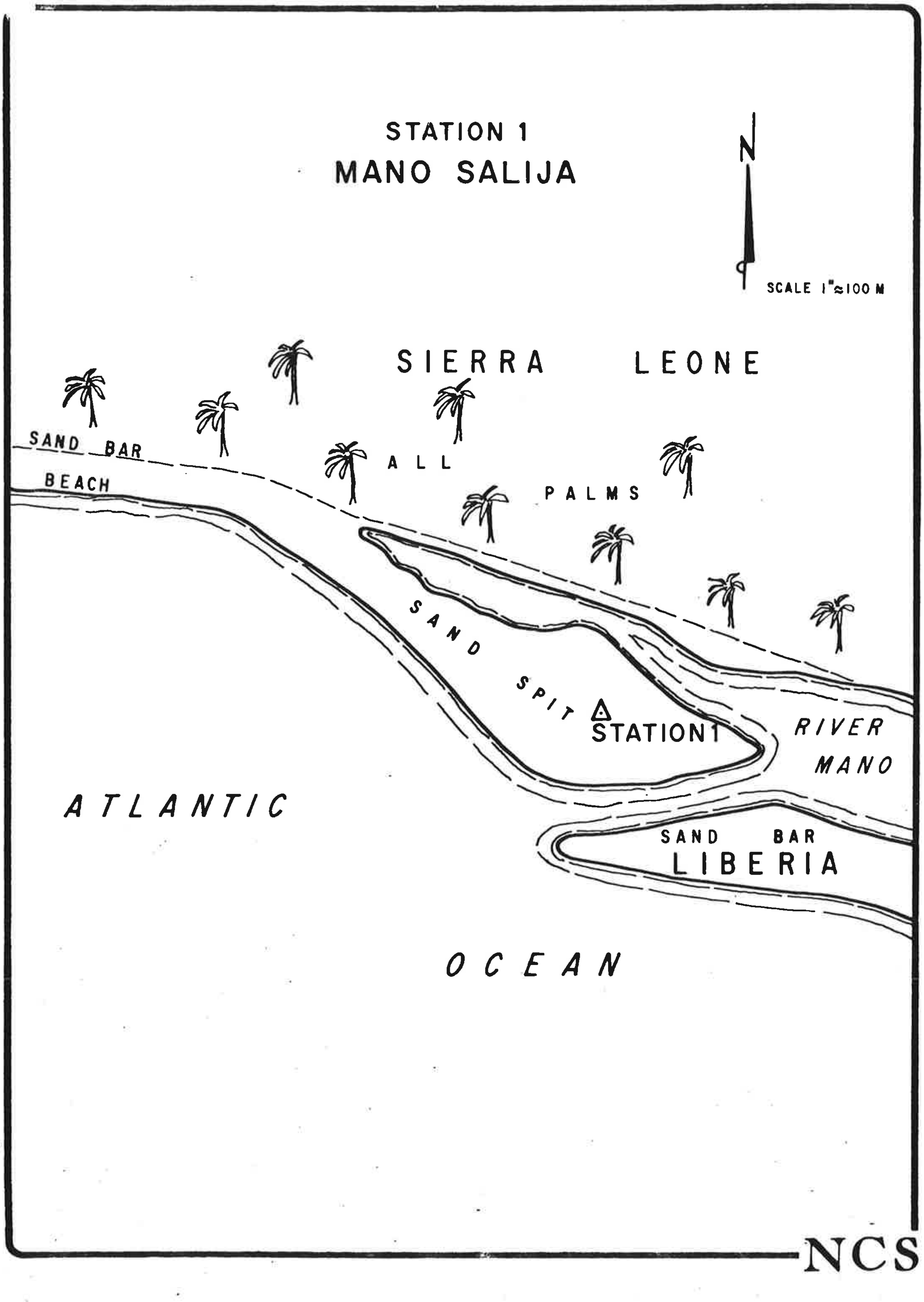
Using Land or Range Rover from Freetown via Bo, Koribundu, Bandajuma, Poturu and Zimi to Sulima then onto the beach southeast for six miles to final sand spit of Sierra Leone, or via helicopter.

Marker :

A galvanized two inch iron pipe set in a cement block 0.5 meters x 0.5 meters and inscribed on top, "Station 1".

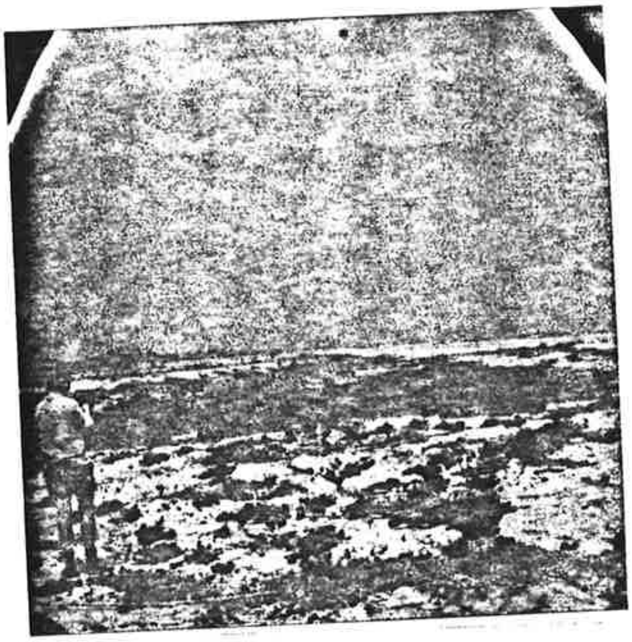
General :

The sand spit of Sierra Leone intrudes into the Mano River to the north in an easterly direction of a sand spit of Liberia to the south which is itself leading westerly in an overlap.

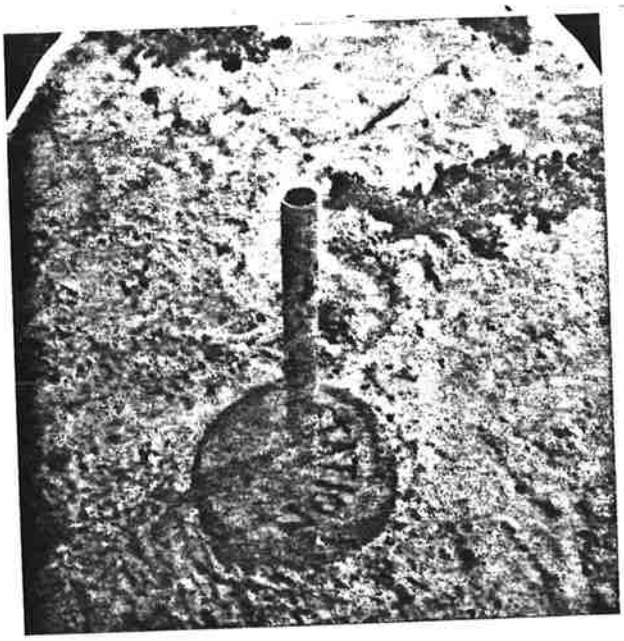

STATION 1
MANO SALIJA
N
SCALE 1"≈100 M
SIERRA LEONE
SAND BAR
BEACH
ALL
PALMS
SAND
SPIT
STATION1
RIVER
MANO
ATLANTIC
SAND BAR
LIBERIA
OCEAN

NCS

STATION 1 - MANO SALIJA



General view (marker in center of picture). Looking east (trees on left) is Liberia.



Iron pipe set in cement inscribed "Station 1".

STATION INFORMATION

Station Name	:	Kasi
Station Number	:	2
Dates Occupied (Mo/Day/Yr)	:	07/12/80 to 07/17/80

Eccentricity (Monument to Antenna)

Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.72 Meters

Station Latitude	:	07 Deg 05 Min 21.598 Sec N
Longitude	:	11 Deg 44 Min 39.329 Sec W
Height	:	41.80 meters
Northing	:	784,520.66 meters
Easting	:	196,838.81 meters
Antenna Latitude	:	07 Deg 05 Min 21.598 Sec N
Longitude	:	11 Deg 44 Min 39.329 Sec W
Height	:	43.52 meters
Northing	:	784,520.66 meters
Easting	:	196,838.81 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	09 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Nearby Geodetic Monument :

Secondary Trigonometrical Point 116X1. Identical with Station 2. Coordinates supplied by Land Surveys office in Freetown.

Latitude	:	07 Deg 05 Min 20.96 Sec N
Longitude	:	11 Deg 44 Min 38.08 Sec W
Northing	:	784,429 meters
Easting	:	196,871 meters
UTM	:	Zone 29

Site Description :

On a sand bar by the beach, backed by low bush and after palm trees. No other topography of note.

Location :

On the eastern end of Turners Peninsula on the south coast of Sierra Leone, one mile from the village of Kasi on Lake Mape.

Access :

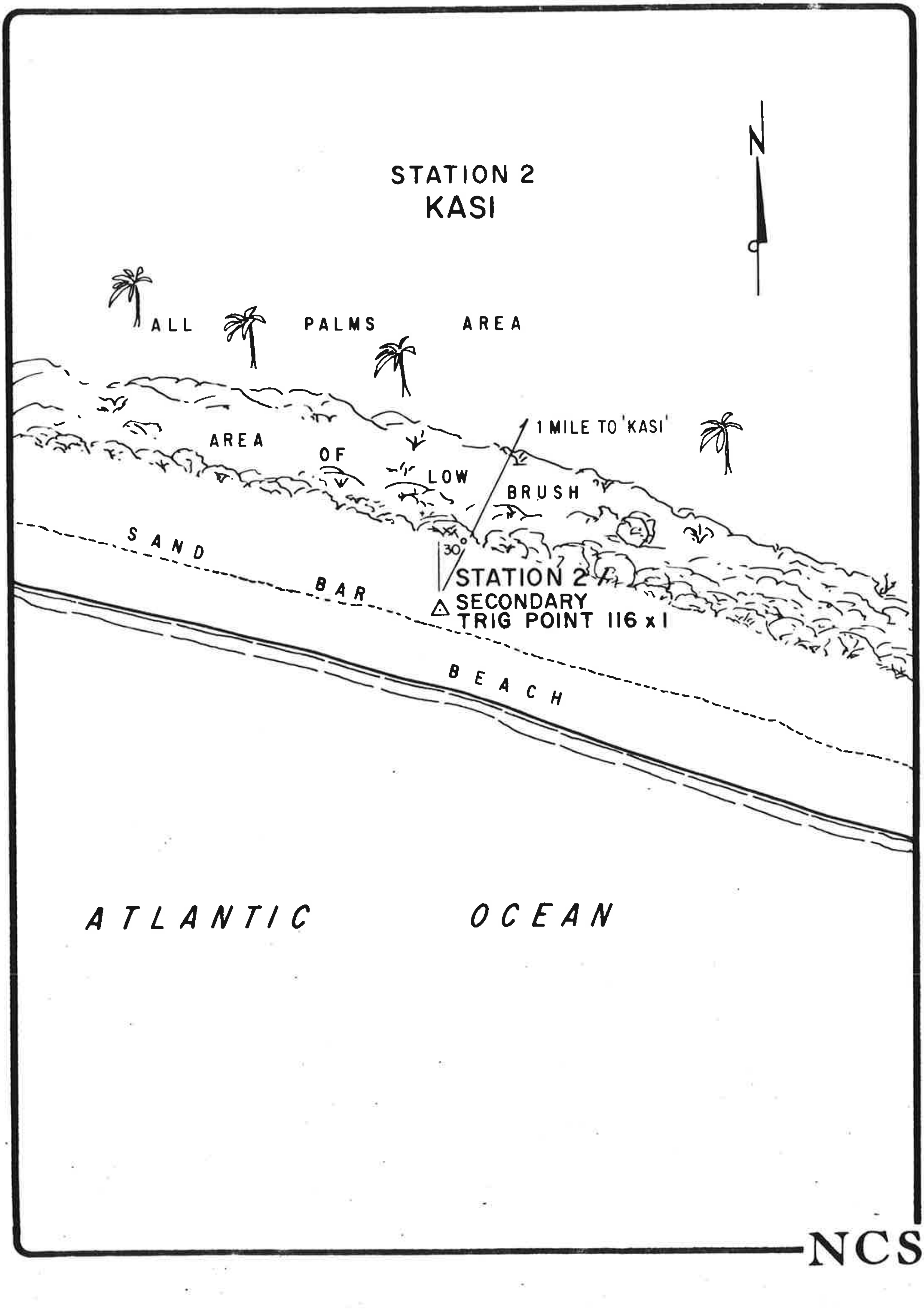
Used helicopter but beach believed drivable from Station #3. Flew overhead Kasi village situated on eastern end of Lake Mape then 210 degrees for exactly one mile to beach.

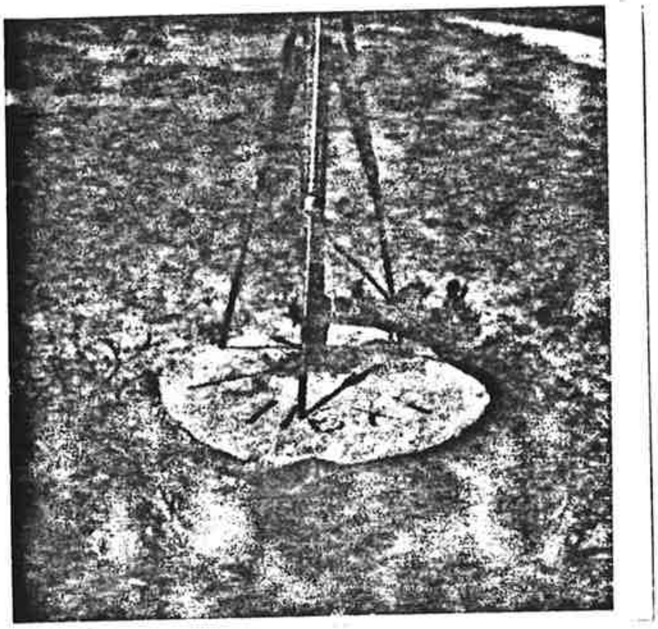
Marker :

A cement filled metal drum erroded halfway up. Set up by D.O.S. as the secondary trigonometrical point number 116 X 1. Height is 4 feet, diameter 2 feet. Inscribed : 116 X 1

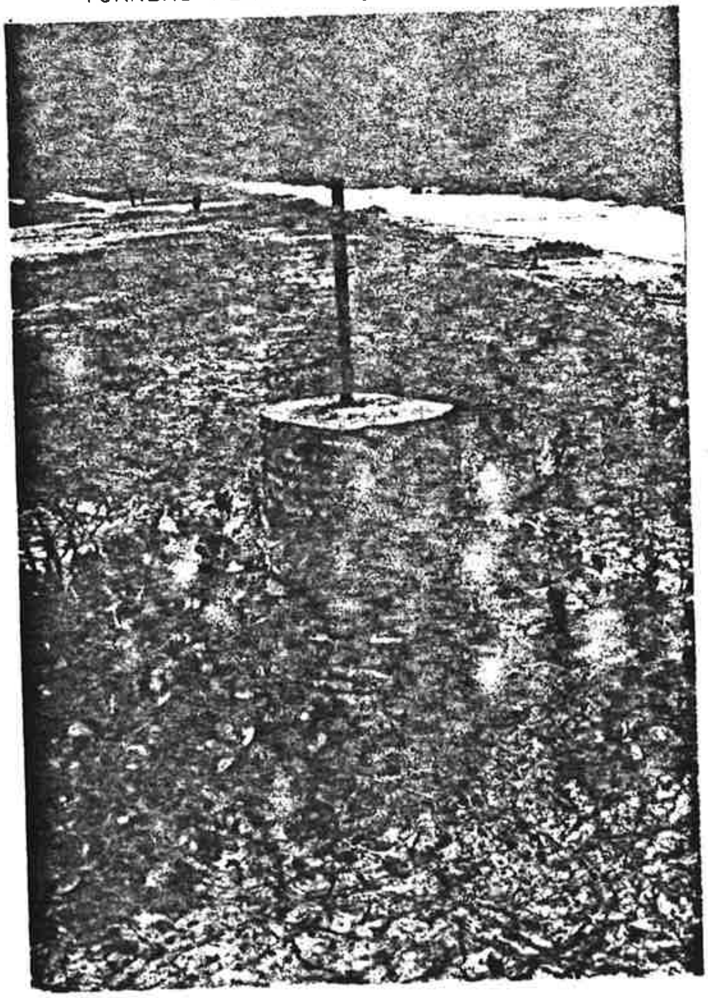
General :

No obstruction. Minimum antenna height for horizontal navigation.


STATION 2
KASI
N
ALL PALMS AREA
1 MILE TO 'KASI'
AREA OF LOW BRUSH
30°
SAND BAR
STATION 2
SECONDARY
TRIG POINT 116 x 1
BEACH
ATLANTIC OCEAN
NCS



STATION 2 - KASI
CEMENT TRIG STATION POINT 116X1
TURNERS PENINSULA, SIERRA LEONE



STATION INFORMATION

Station Name	:	Bengani
Station Number	:	3
Dates Occupied (Mo/Day/Yr)	:	07/09/80 to 07/12/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	0.50 Meters
Station Latitude	:	07 Deg 09 Min 47.666 Sec N
Longitude	:	11 Deg 53 Min 36.375 Sec W
Height	:	41.80 meters
Northing	:	792,801.35 meters
Easting	:	180,396.76 meters
Antenna Latitude	:	07 Deg 09 Min 47.666 Sec N
Longitude	:	11 Deg 53 Min 36.375 Sec W
Height	:	42.30 meters
Northing	:	792,801.35 meters
Easting	:	180,396.76 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	09 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

On a sand bar by the sea, backed by low bush and then palms.

Location :

On the beach 2 miles from the village of Bengani, 7 1/3 miles from Mesima/Senehun, travelling east.

Access :

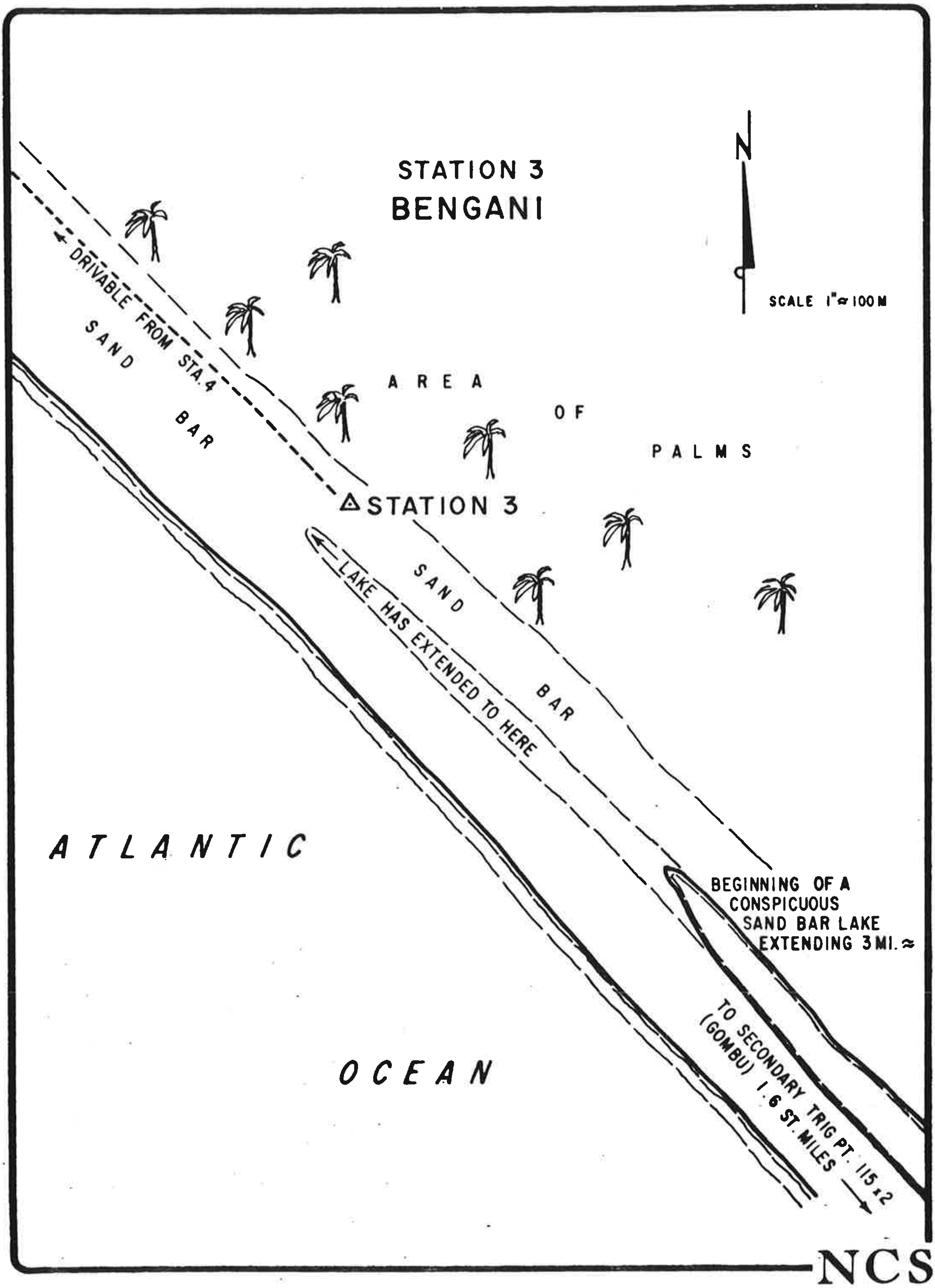
Use a Land or Range Rover from Freetown to Bo, Pujehan and Gbundapi. From there use the Ministry of Agriculture ferry south on the Malen and Waanje Rivers to Mesima/Senehun. Then via the beach eastward 7 1/3 miles to the site, or via helicopter.

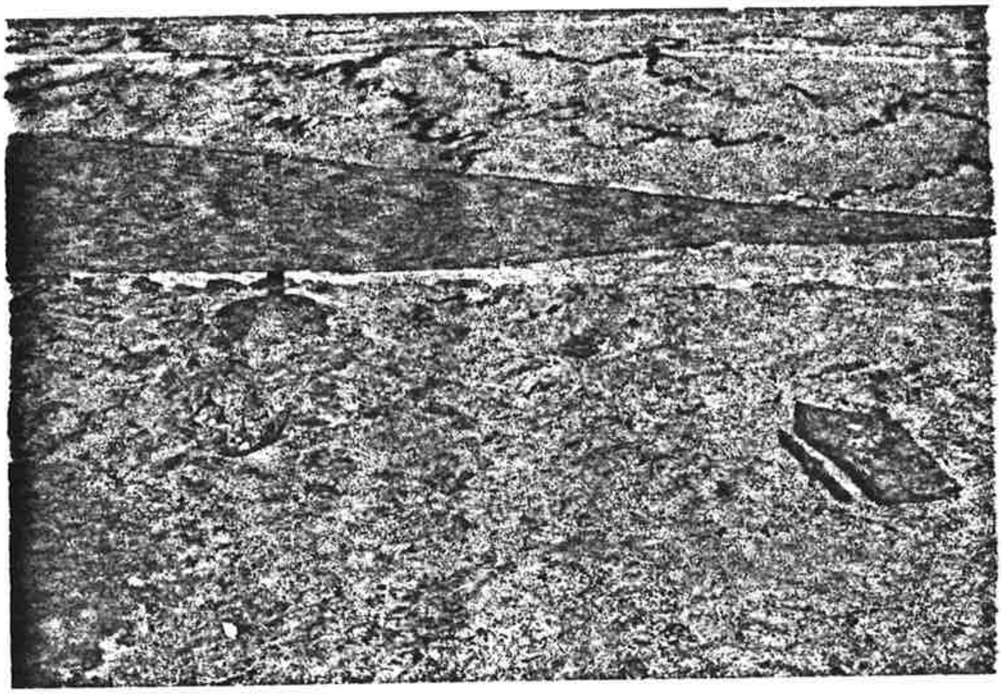
Marker :

A galvanized steel pipe inset into a round cement block 0.5 meters x 0.5 meters and inscribed on top, "Station 3".

General :

No obstruction. Minimum antenna height for horizontal navigation.


STATION 3
BENGANI
N
SCALE 1"≈100M
DRIVABLE FROM STA.4
SAND BAR
AREA OF PALMS
STATION 3
SAND BAR
LAKE HAS EXTENDED TO HERE
BEGINNING OF A CONSPICUOUS SAND BAR LAKE EXTENDING 3MI.≈
TO SECONDARY TRIG PT. 115±2 (GOMBU) 1.6 ST. MILES
ATLANTIC
OCEAN
NCS



STATION 3 - BENGANI
Cement and iron pipe inscribed "STATION 3".
Turners Peninsula, Sierra Leone

STATION INFORMATION

Station Name	:	Mano Curanco
Station Number	:	4
Dates Occupied (Mo/Day/Yr)	:	07/04/80 to 07/09/80

Eccentricity (Monument to Antenna)

Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	2.33 Meters

Station Latitude	:	07 Deg 14 Min 27.381 Sec N
Longitude	:	12 Deg 05 Min 04.331 Sec W
Height	:	42.72 meters
Northing	:	801,417.00 meters
Easting	:	821,983.33 meters
Antenna Latitude	:	07 Deg 14 Min 27.381 Sec N
Longitude	:	12 Deg 05 Min 04.331 Sec W
Height	:	45.05 meters
Northing	:	801,417.00 meters
Easting	:	821,983.33 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Nearby Geodetic Monument :

Secondary Trigonometrical Point 114X1. Identical with Station 4. Coordinates supplied by Land Surveys office in Freetown.

Latitude	:	07 Deg 14 Min 26.73 Sec N
Longitude	:	12 Deg 05 Min 03.08 Sec W
Northing	:	801,324 meters
Easting	:	822,028 meters
UTM	:	Zone 28

Site Description :

A grass covered sand bar by the sea backed by low brush and then palms.

Location :

On the beach near (500 yards) the two villages of Mano and Kuranko which are situated on the River Waanje at its closest to the sea. The land area is Turners Peninsula.

Access :

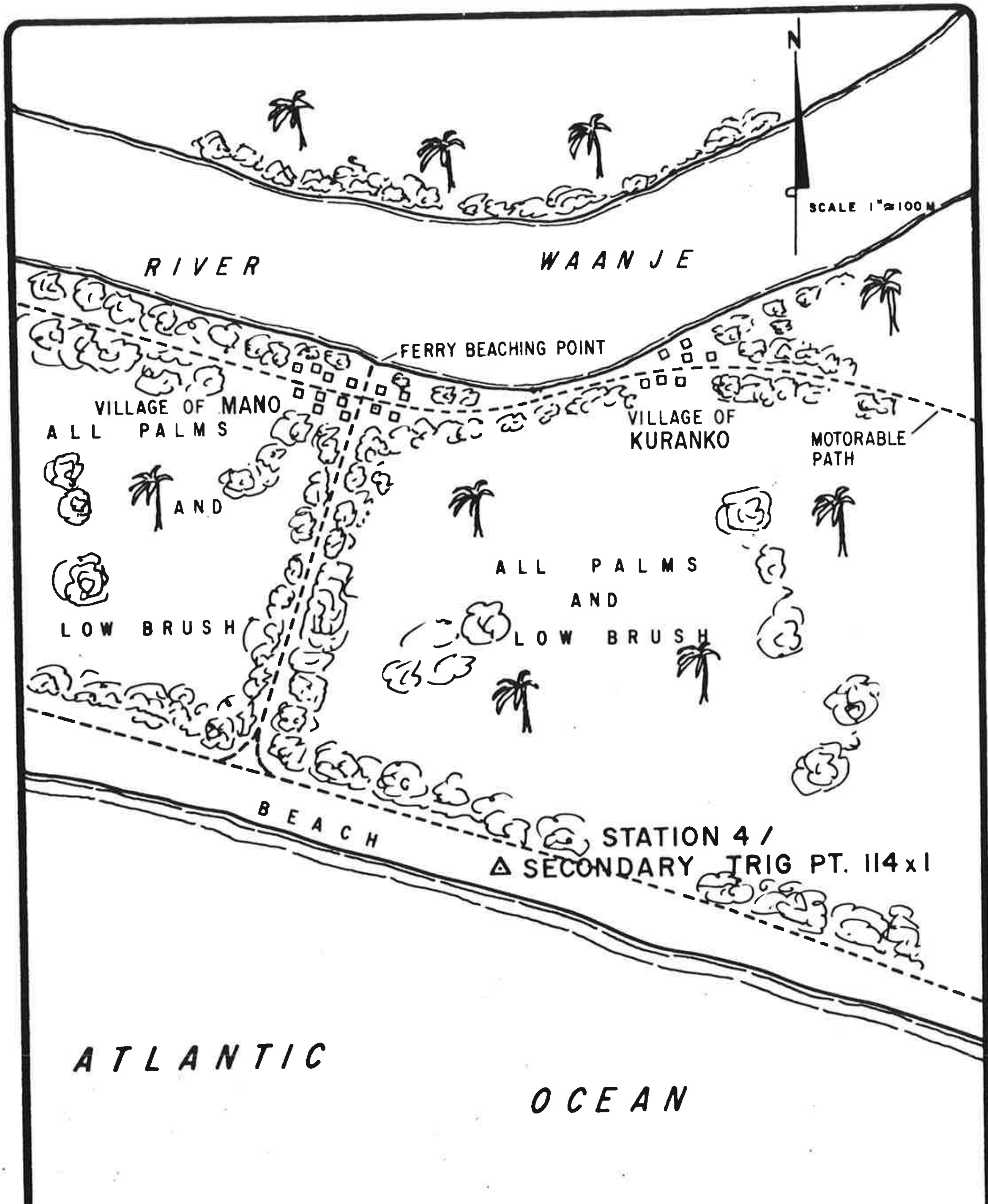
Use Land or Range Rover from Freetown via Bo, Pujehan and to Gbundapi. From there use the Ministry of Agriculture ferry on the Malen and Waanje Rivers to Mesima/Senehun and then either via inland path (motorable) or beach (motorable) west 8 miles to Mano and Kurankoo, or by helicopter.

Marker :

The marker is identical to secondary trig point "114 X 1" which consists of a cement filled column comprising two metal drums welded together, 6 feet high and 2 feet in diameter. There are no inscriptions on the marker.

General :

No obstructions. Minimum antenna height for horizontal navigation.



STATION 4
KURANKO

STATION INFORMATION

Station Name	:	Yile
Station Number	:	5
Dates Occupied (Mo/Day/Yr)	:	06/25/80 to 07/04/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	0.50 Meters
Station Latitude	:	07 Deg 19 Min 52.490 Sec N
Longitude	:	12 Deg 19 Min 03.237 Sec W
Height	:	42.12 meters
Northing	:	811,252.32 meters
Easting	:	796,169.07 meters
Antenna Latitude	:	07 Deg 19 Min 52.490 Sec N
Longitude	:	12 Deg 19 Min 03.237 Sec W
Height	:	42.62 meters
Northing	:	811,252.32 meters
Easting	:	796,169.07 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

On a sand bar ridge on the beach with low bush and palms to landwards.

Location :

About 25 miles from Mesima/Senehun and 15 miles from the western end of Turners Peninsula.

Access :

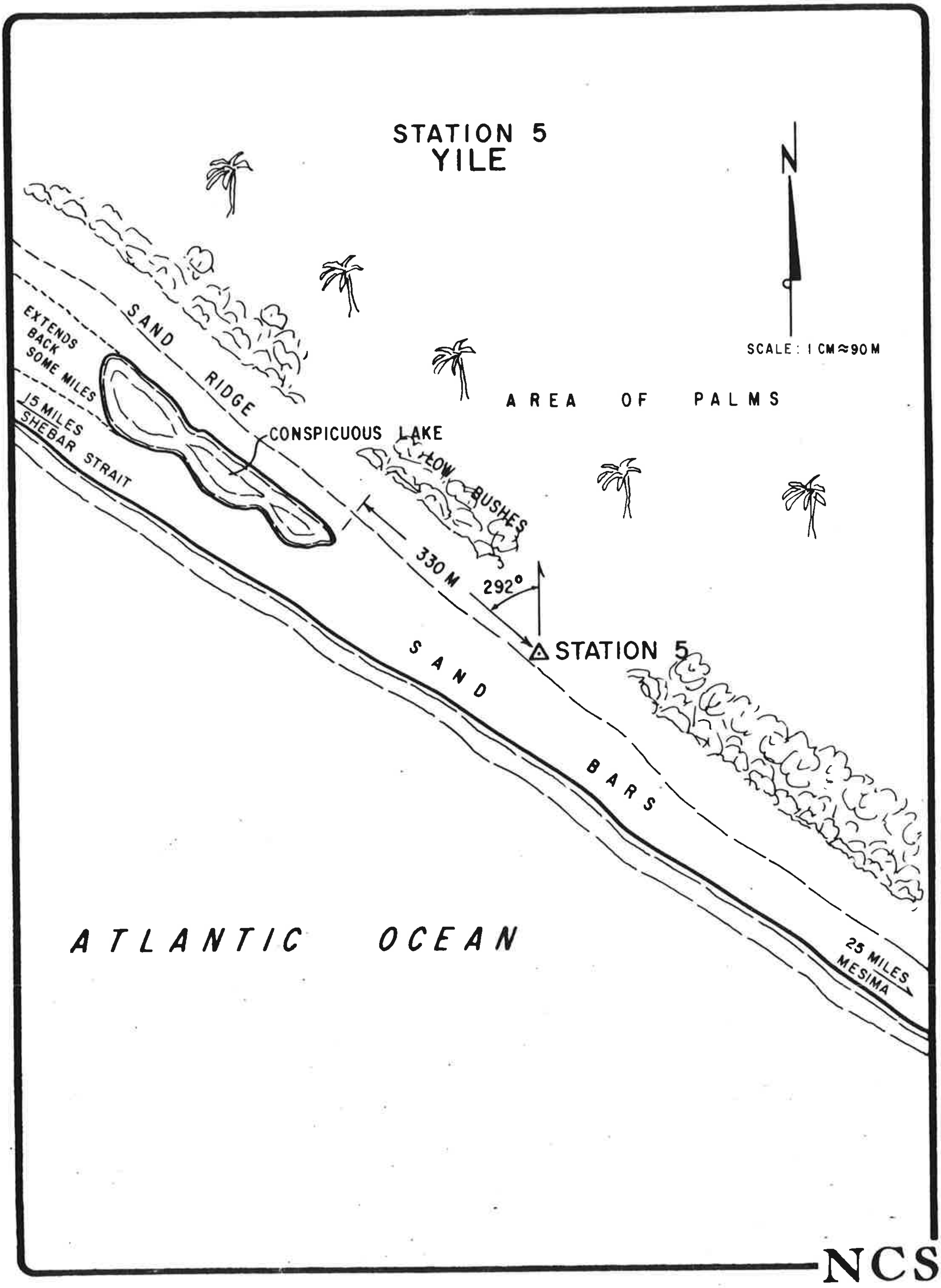
Using Land or Range Rover from Freetown via Bo, Pujehan and then to Gbundapi, from there using the Ministry of Agriculture ferry south on the Malen and Waanje Rivers to Mesima/Senehun on Turners Peninsula. Then via the beach motoring west past Station 4 (Mano Curanco) to the site, or by helicopter.

Marker :

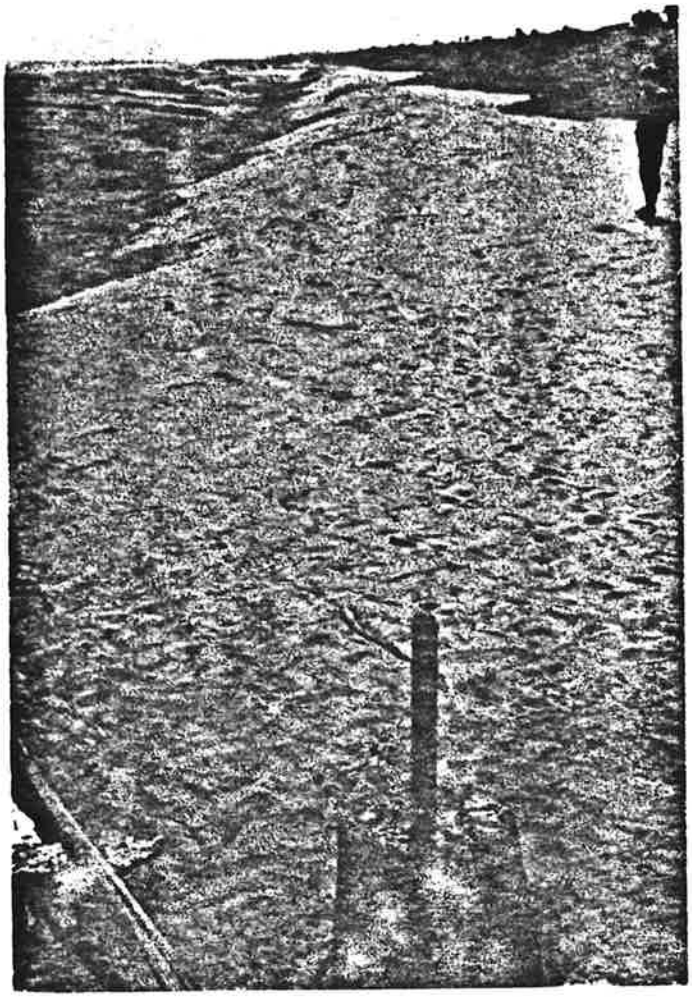
A galvanized 22 inch steel pipe set into a round cement block 0.5 X 0.5 meters and inscribed on the top : "Station 5".

General :

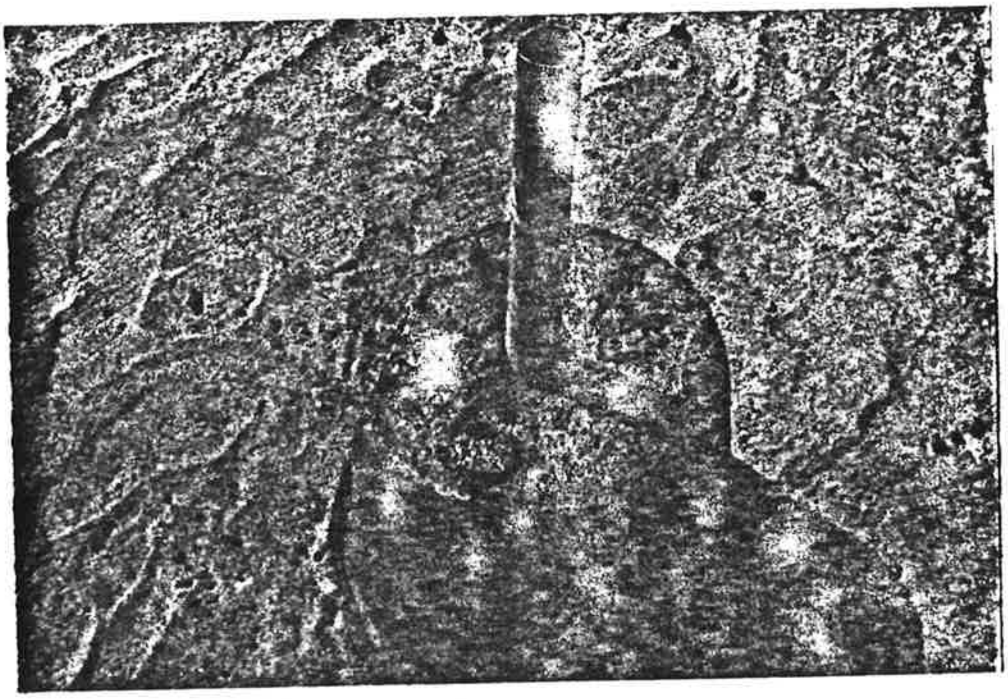
No obstructions. Minimum antenna height for horizontal navigation.


STATION 5
YILE
N
SCALE: 1 CM ≈ 90 M
SAND RIDGE
EXTENDS BACK SOME MILES
15 MILES SHEBAR STRAIT
CONSPICUOUS LAKE
LOW BUSHES
AREA OF PALMS
330 M
292°
STATION 5
SAND BARS
ATLANTIC OCEAN
25 MILES MESIMA

NCS



STATION 5 - YILE
Cement and iron pipe
inscribed "STATION 5".
Turners Peninsula, Sierra Leone



STATION INFORMATION

Station Name :	Shebar
Station Number :	6
Dates Occupied (Mo/Day/Yr) :	05/31/80 to 06/07/80
Eccentricity (Monument to Antenna)	
Horizontal :	N/A
Bearing :	N/A
Vertical (up +) :	0.50 Meters
Station Latitude :	07 Deg 23 Min 26.048 Sec N
Longitude :	12 Deg 32 Min 49.968 Sec W
Height :	41.32 meters
Northing :	817,670.90 meters
Easting :	770,761.74 meters
Antenna Latitude :	07 Deg 23 Min 26.048 Sec N
Longitude :	12 Deg 32 Min 49.968 Sec W
Height :	41.82 meters
Northing :	817,670.90 meters
Easting :	770,761.74 meters
Spheroid Name :	WGS-72
Datum :	Geocentric
Projection :	Universal Transverse Mercator
Central Meridian :	15 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

Site located on open ground with some palms; a cultivated area.

Location :

Approximately 1 1/2 kilometers from Mania village on the extreme southernly part of Sherbro Island.

Access :

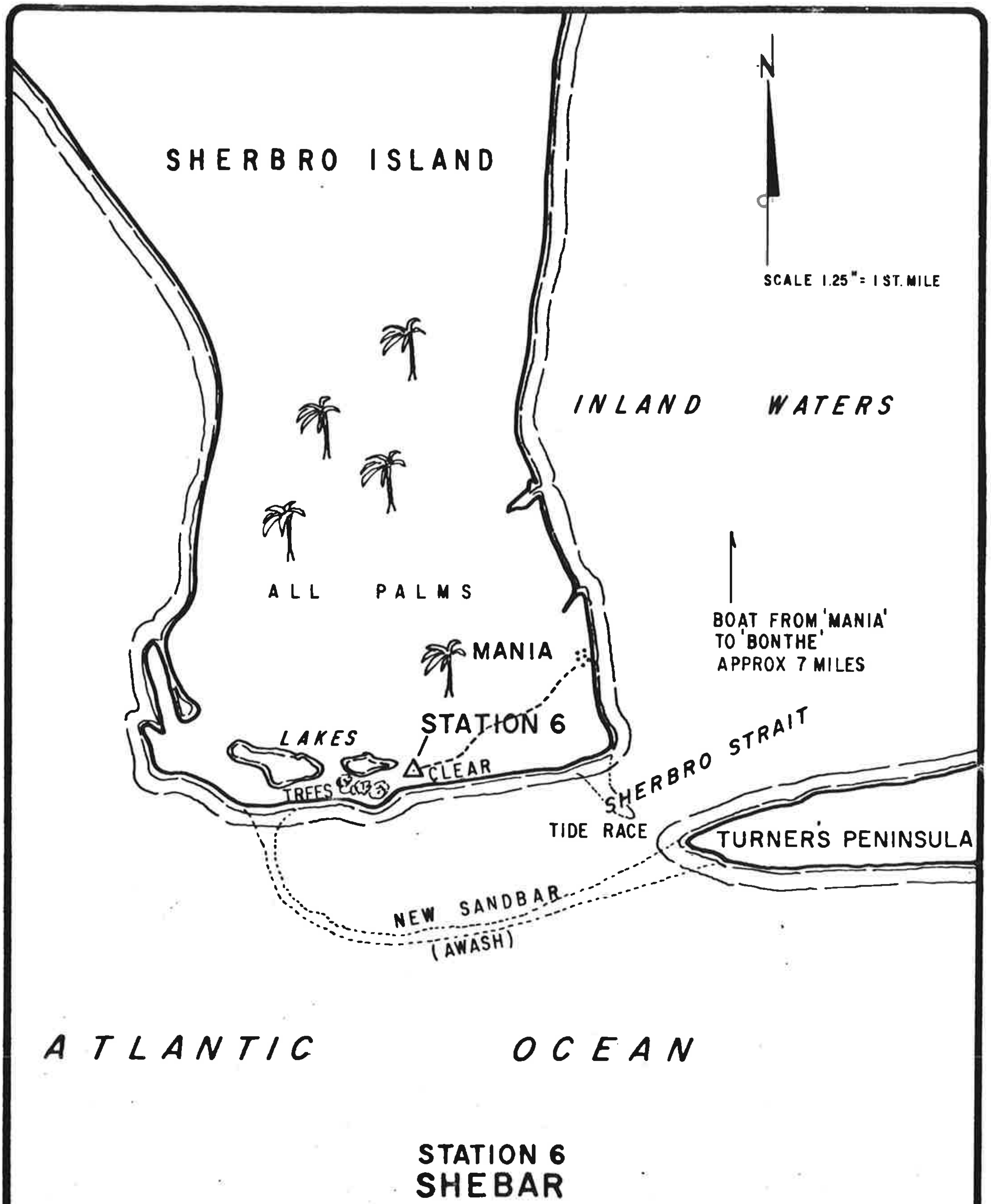
From Freetown to Bonthe via light plane (scheduled), then via speedboat (50 Leones per day) to Mania village, 7 miles south. Enroute a visit to the Paramount chief at Yoni village, Mr. George J.R. Brandon, is suggested. Mr. Burrah-Kallah, section chief at Mania, will guide you to the marker.

Marker :

A galvanized steel pipe set into a 0.5 X 0.5 meter round cement block and inscribed on top : "Station 6".

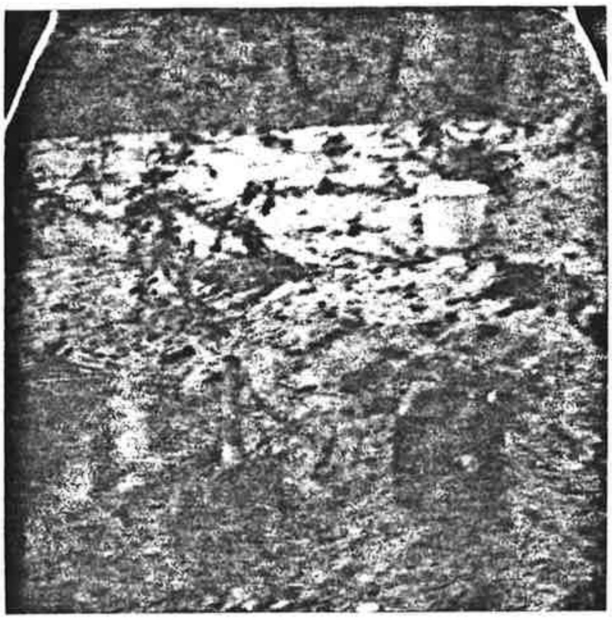
General :

Secondary trig marker No. 106-1, known to be washed away. Maximum horizontal antenna required is 40 feet.



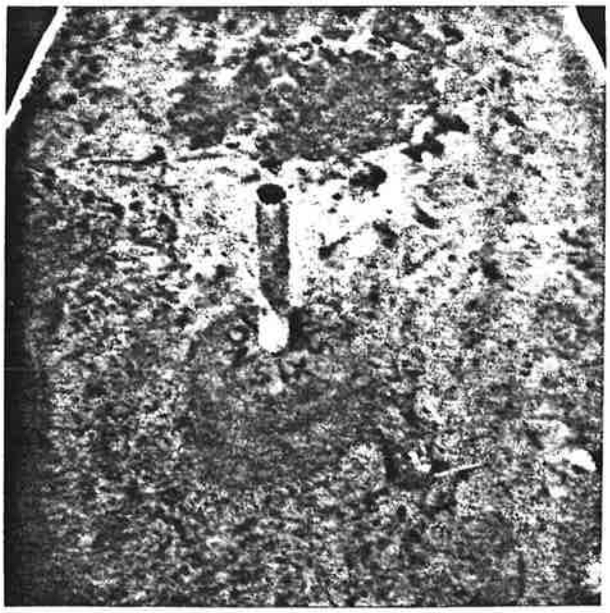
STATION 6
SHEBAR

NCS



STATION 6 - SHEBAR

Cement and iron pipe inscribed "STATION 6". Sherbro Island, Sierra Leone



STATION INFORMATION

Station Name	:	Cape St. Ann
Station Number	:	7
Dates Occupied (Mo/Day/Yr)	:	06/09/80 to 06/13/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.11 Meters
Station Latitude	:	07 Deg 34 Min 18.527 Sec N
Longitude	:	12 Deg 57 Min 11.831 Sec W
Height	:	40.19 meters
Northing	:	837,493.04 meters
Easting	:	725,821.86 meters
Antenna Latitude	:	07 Deg 34 Min 18.527 Sec N
Longitude	:	12 Deg 57 Min 11.831 Sec W
Height	:	41.30 meters
Northing	:	837,493.04 meters
Easting	:	725,821.86 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

Site located on open ground with some palms. Old sand bars or ridges nearby.

Location :

Approximately 2 kilometers from Tisana village on the extreme west end of Sherbro Island.

Access :

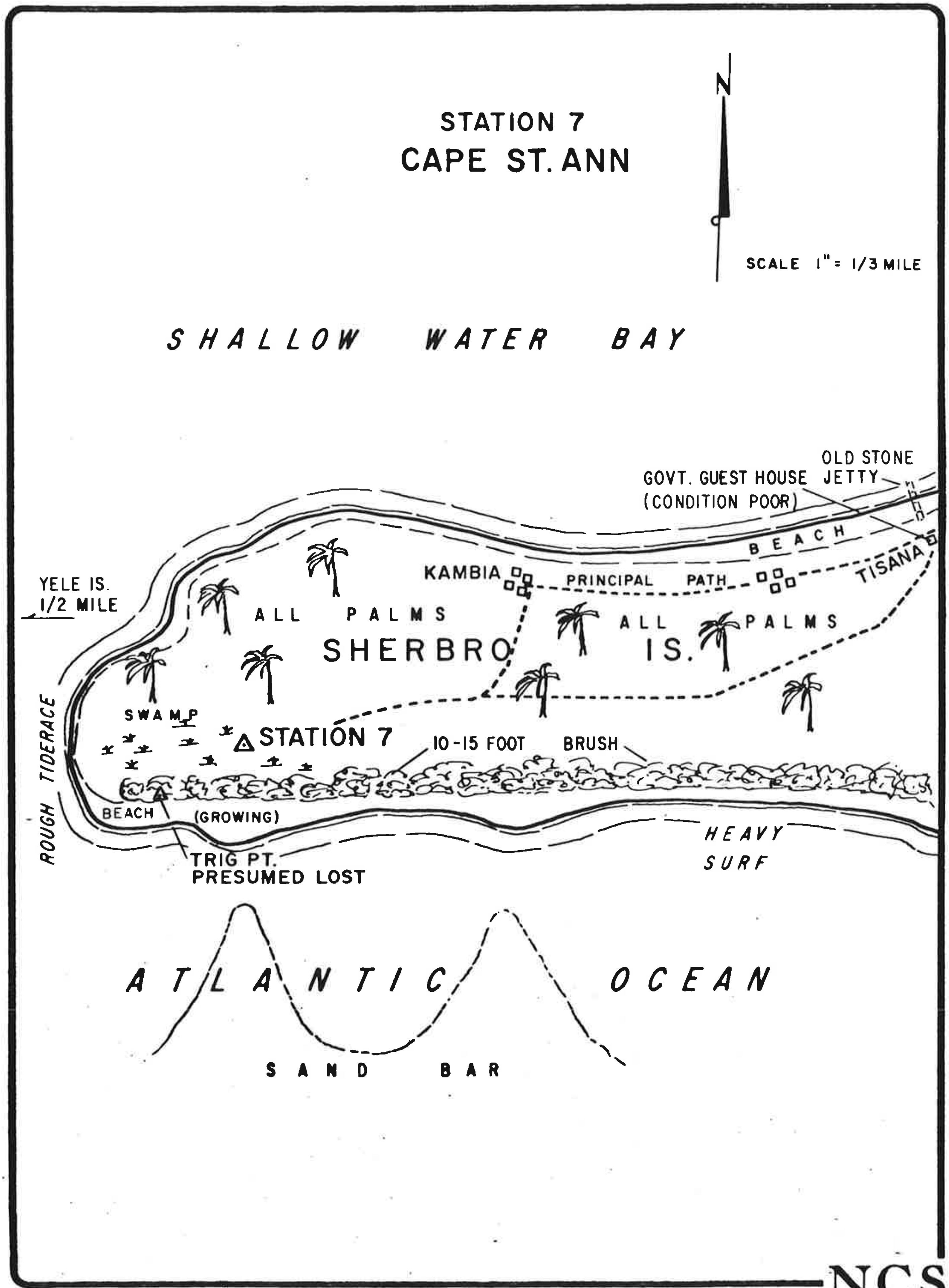
From Freetown to Bonthe via light plane (scheduled), then via launch (contact Mr. Farma, 120 Leones per day) to Tisana (5 hours)). See Paramount Chief George Ngbay or Treasurer Alfred Soloman. Hire area Chief of Kambia village, Kaing Borda, as guide to the site.

Marker :

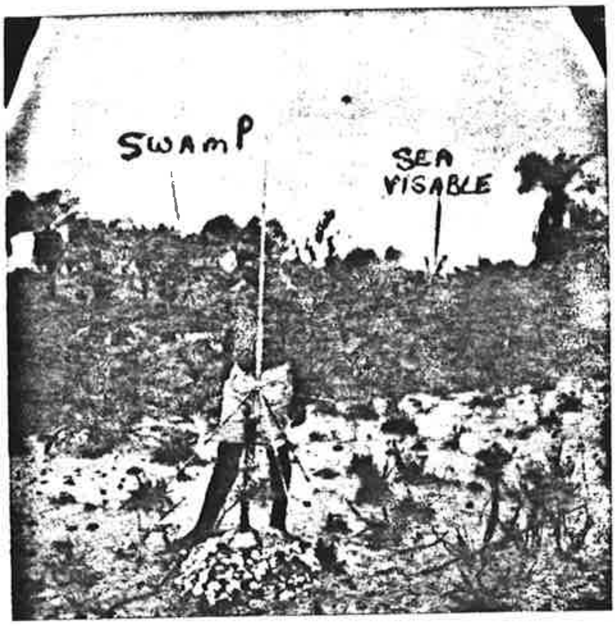
Small mound of cement and shell mix about 1 foot high with 1 1/2 inch diameter hole in center (2 feet in diameter). There are no inscriptions on the marker.

General :

Secondary trig marker No. 96-1 lost in 10 foot brush. Believed still there. Site would require maximum of 40 foot antenna for <u>all</u> sea work.

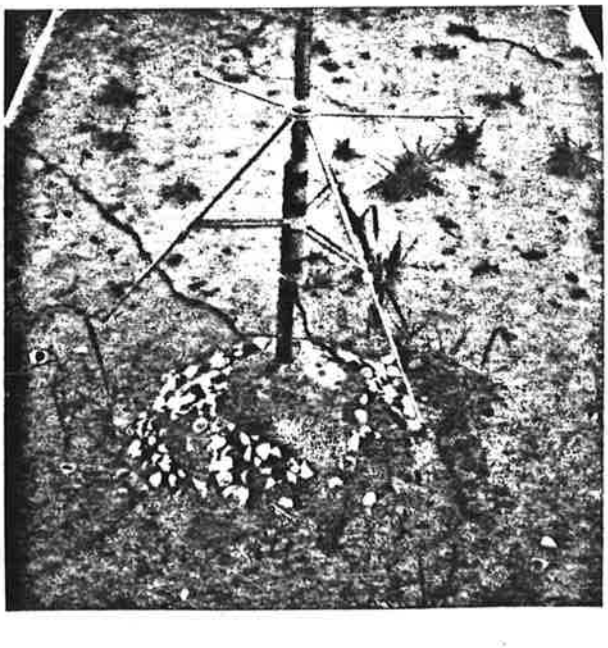

STATION 7
CAPE ST. ANN
N
SCALE 1" = 1/3 MILE
SHALLOW WATER BAY
OLD STONE JETTY
GOVT. GUEST HOUSE (CONDITION POOR)
BEACH
KAMBIA
PRINCIPAL PATH
TISANA
YELE IS. 1/2 MILE
ALL PALMS
SHERBRO IS.
ALL PALMS
SWAMP
STATION 7
10-15 FOOT BRUSH
ROUGH TIDERACE
BEACH
(GROWING)
TRIG PT. PRESUMED LOST
HEAVY SURF
ATLANTIC OCEAN
SAND BAR

NCS



STATION 7 - CAPE ST. ANN

Marker is made of cement and shell mix.



STATION INFORMATION

Station Name	:	Shenge
Station Number	:	8
Dates Occupied (Mo/Day/Yr)	:	05/23/80 to 06/05/80

Eccentricity (Monument to Antenna)

Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	0.50 Meters

Station Latitude	:	07 Deg 54 Min 59.211 Sec N
Longitude	:	12 Deg 57 Min 38.358 Sec W
Height	:	44.78 meters
Northing	:	875,612.04 meters
Easting	:	724,825.59 meters
Antenna Latitude	:	07 Deg 54 Min 59.211 Sec N
Longitude	:	12 Deg 57 Min 38.358 Sec W
Height	:	45.28 meters
Northing	:	875,612.04 meters
Easting	:	724,825.59 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Nearby Geodetic Monument :

Primary trigonometrical point is SPLT 22. Coordinates for SLPT 22 supplied by Land Surveys in Freetown. Eccentricity bearing is magnetic corrected for variation.

Eccentricity (NCSI 8 to SLPT 22) :

Horizontal	:	86.7 meters
Bearing	:	278.6 degrees true
Latitude	:	07 Deg 54 Min 59.1019 Sec N
Longitude	:	12 Deg 57 Min 39.8721 Sec W
Northing	:	875,528.8424 meters
Easting	:	724,783.4831 meters
Height	:	25 feet
Semi-Major Axis	:	6,378,249.145 meters

Site Description :

The site is near the beach on open ground. The area at this time is clear of brush and the trig marker, SLPT 22, can now be seen.

Location :

The marker is at Shenge Point near the village of Shenge some 77 kilometers from Freetown.

Access :

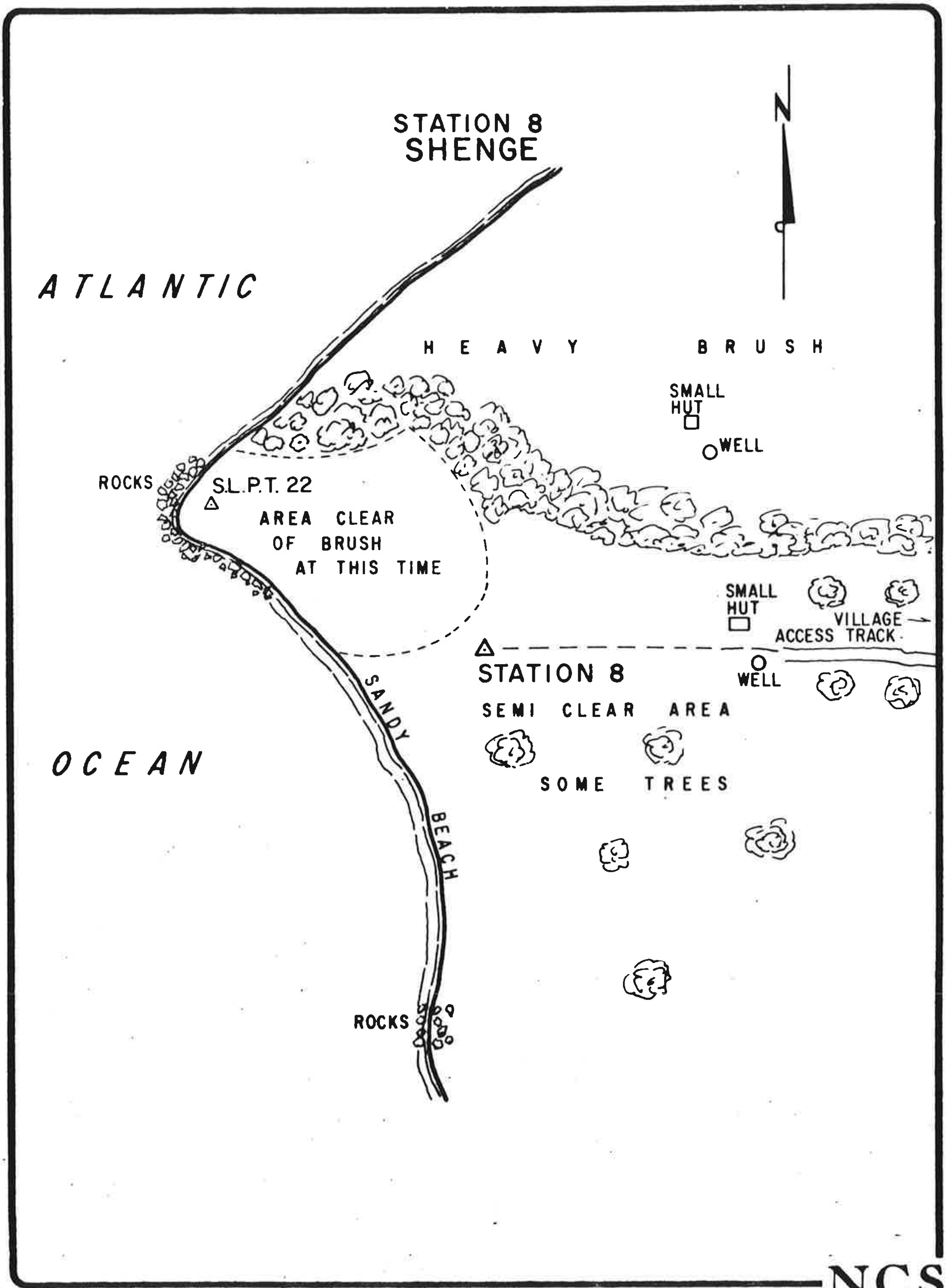
From Freetown take the road to Moyamba junction (156 kilometers). Turn right towards Moyamba (35 kilometers). AT Moyamba, turn left at the Mobil station and follow this road which curves to the right to Shenge (184 kilometers).

Marker :

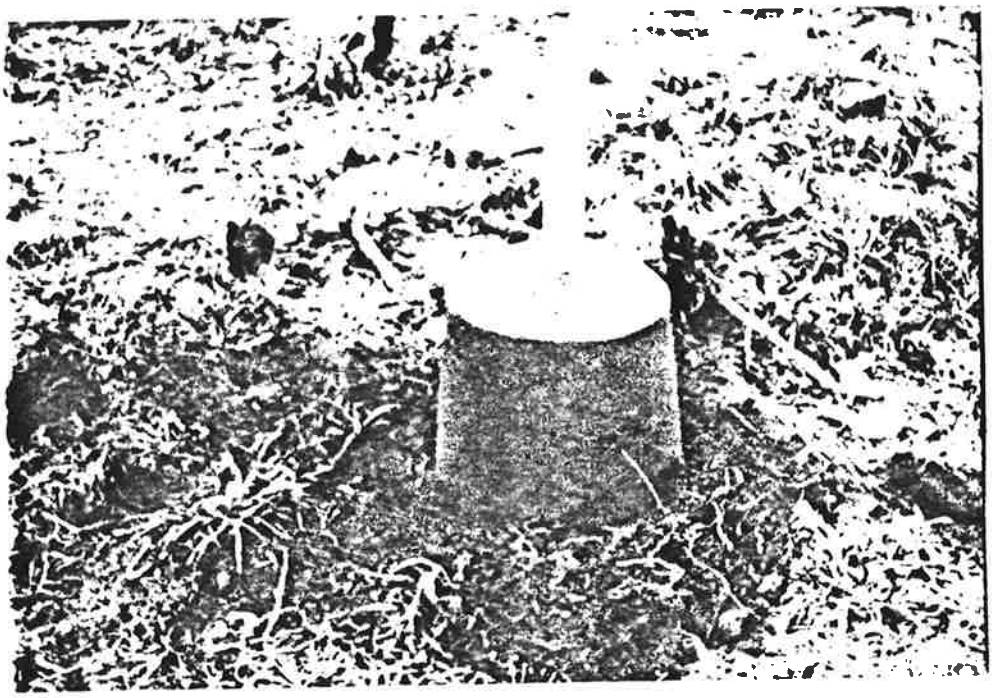
A galvanized steel pipe set into a 0.5 meter X 0.5 meter round cement block inscribed "Station 8".

General :

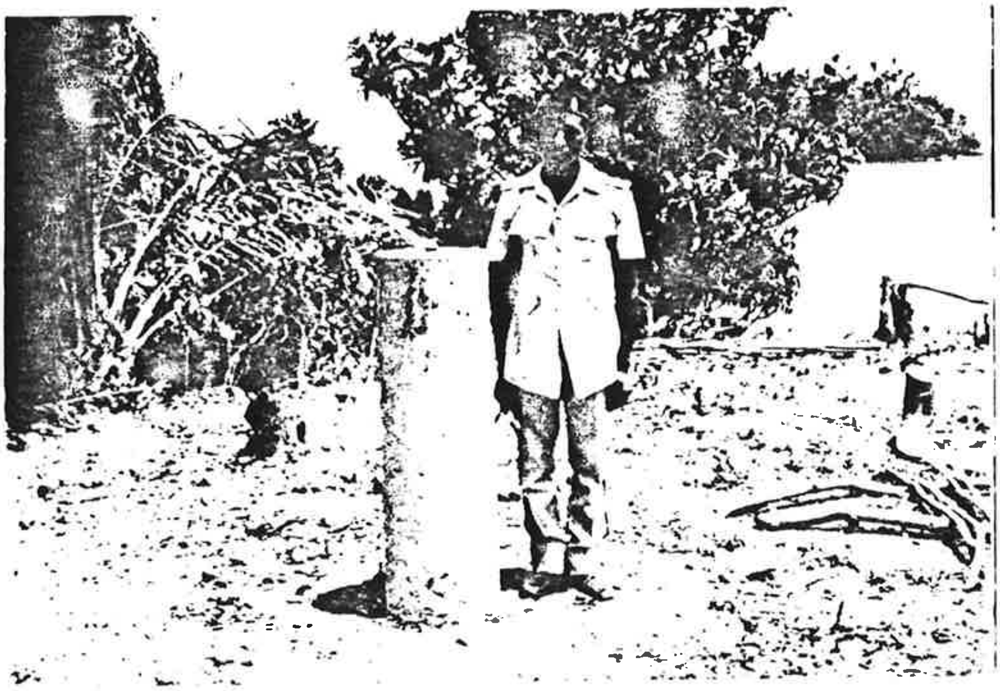
Contact Shenge Paramount Chief, Madam Bailor-Caulker. Total distance from Shenge to Freetown is 279 kilometers (about 4 hours drive). Area clear south to 300 degrees from Station 8; thereafter a 40 foot tower is required. All clear from SLPT 22, minimum height required.


STATION 8
SHENGE
ATLANTIC
OCEAN
HEAVY BRUSH
SMALL HUT
WELL
ROCKS
S.L.P.T. 22
AREA CLEAR OF BRUSH AT THIS TIME
SMALL HUT
VILLAGE ACCESS TRACK
STATION 8
WELL
SEMI CLEAR AREA
SOME TREES
SANDY BEACH
ROCKS
N

NCS

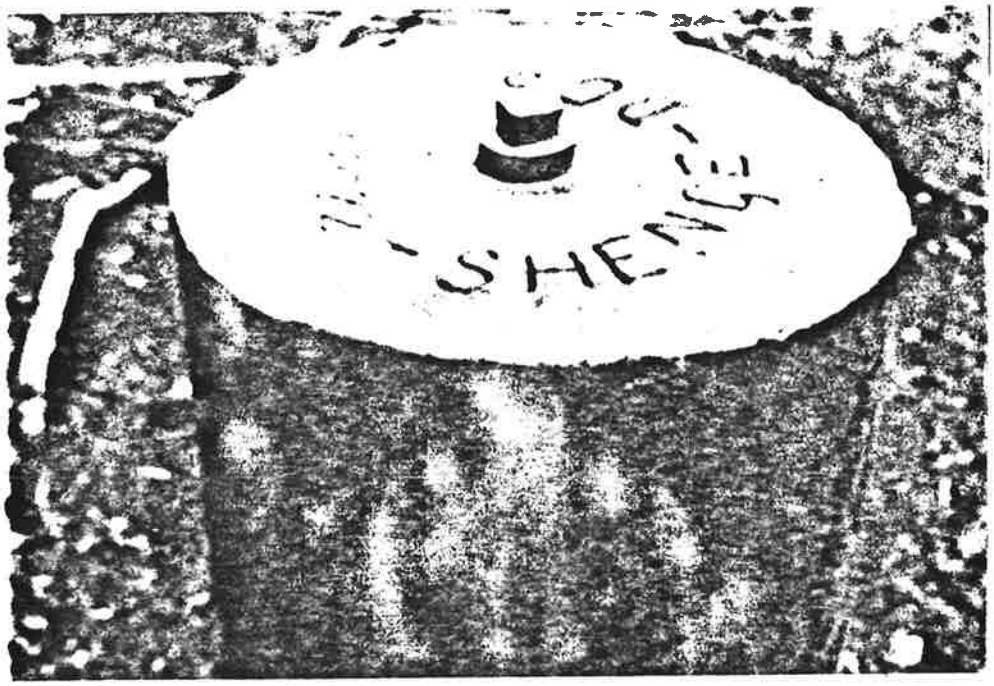


STATION 8 - SHENGE



SIERRA LEONE

PRIMARY TRIGONOMETRICAL POINT 22



STATION INFORMATION

Station Name	:	Cape Shilling
Station Number	:	9
Dates Occupied (Mo/Day/Yr)	:	05/28/80 to 06/13/80 06/30/80 to 07/28/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.11 Meters
Station Latitude	:	08 Deg 10 Min 25.329 Sec N
Longitude	:	13 Deg 09 Min 51.182 Sec W
Height	:	48.09 meters
Northing	:	903,961.56 meters
Easting	:	702,248.59 meters
Antenna Latitude	:	08 Deg 10 Min 25.329 Sec N
Longitude	:	13 Deg 09 Min 51.182 Sec W
Height	:	49.20 meters
Northing	:	903,961.56 meters
Easting	:	702,248.59 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees W

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

The site is some 100 meters from the beach within the grounds of the police post. The immediate area is clear but some trees nearby do cause obstruction. A minimum tower height of 60 feet is needed.

Location :

The marker is situated at Cape Shilling near the village of Kent some 37 kilometers south southeast of Freetown.

Access :

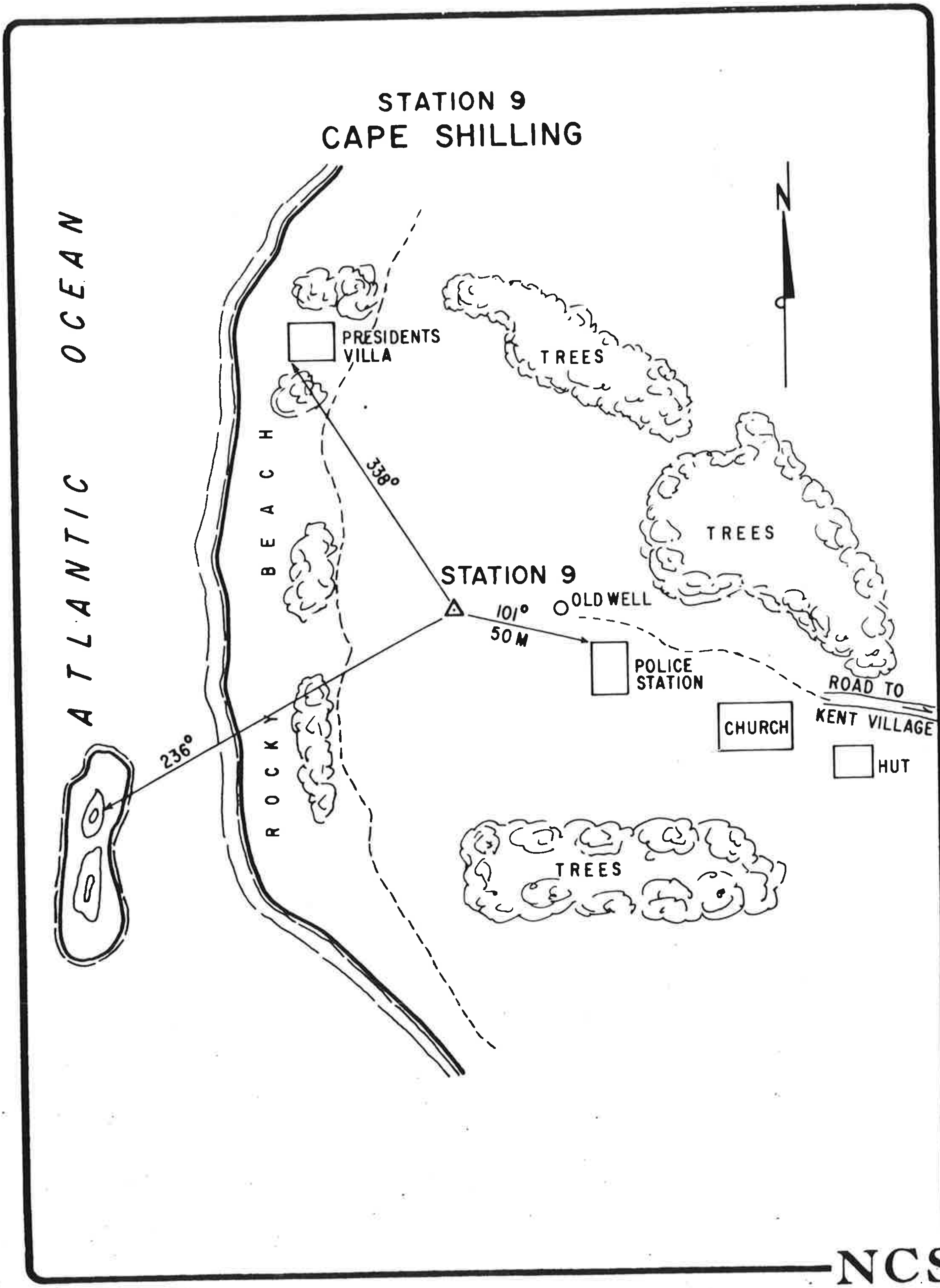
From Freetown, take the road to Waterloo (29 kilometers). Turn right just before the local market and follow the rough road for 20 kilometers. When the road branches, take the left fork. There will be a sign posted, "Kent". The marker is on the west side of Kent village.

Marker :

A galvanized steel pipe set into a 0.5 X 0.5 meter round cement block inscribed "Station 9".

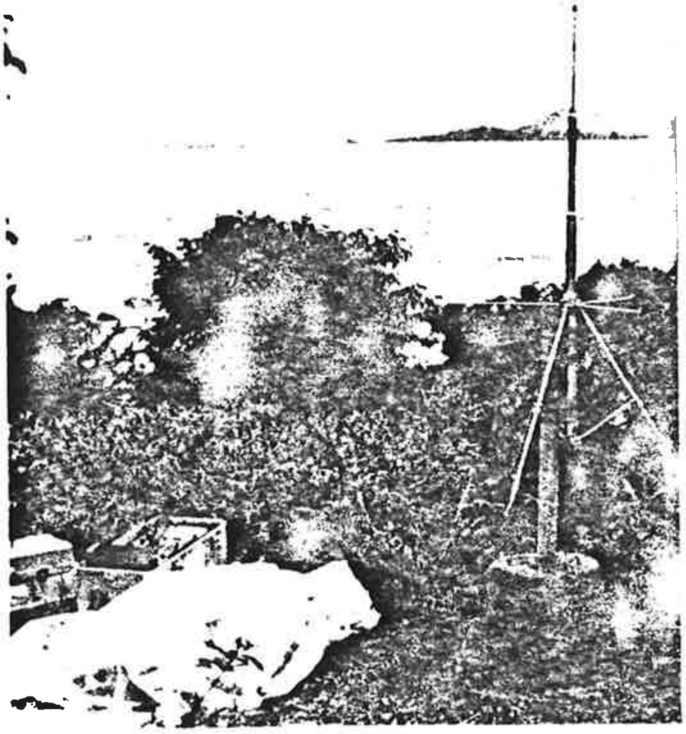
General :

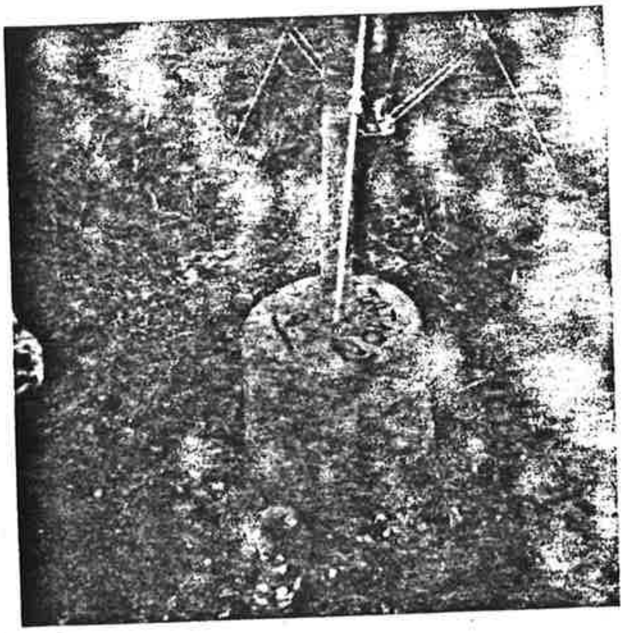
This area has lots of tall trees, therefore, a 70 foot antenna minimum would be required for horizontal navigation. There is plenty of clear space for layout, etc...


STATION 9
CAPE SHILLING
ATLANTIC OCEAN
N
PRESIDENTS VILLA
TREES
338°
BEACH
TREES
STATION 9
OLD WELL
101°
50 M
POLICE STATION
ROAD TO KENT VILLAGE
CHURCH
HUT
236°
ROCKY
TREES

NCS

STATION 9 - CAPE SHILLING
Site located at Kent village,
Cape Shilling.





Cement and iron pipe
inscribed "STATION 9".

STATION INFORMATION

Station Name	:	Cape Sierra
Station Number	:	10
Dates Occupied (Mo/Day/Yr)	:	05/24/80 to 05/28/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.11 Meters
Station Latitude	:	08 Deg 29 Min 45.145 Sec N
Longitude	:	13 Deg 17 Min 48.561 Sec W
Height	:	57.88 meters
Northing	:	939,529.65 meters
Easting	:	687,481.53 meters
Antenna Latitude	:	08 Deg 29 Min 45.145 Sec N
Longitude	:	13 Deg 17 Min 48.561 Sec W
Height	:	58.99 meters
Northing	:	939,529.65 meters
Easting	:	687,481.53 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

The site lies on high ground about 400 meters from the sea. The immediate area has some brush, therefore, a minimum height tower is required.

Location :

The marker is situated at Aberdeen 5 kilometers west of Freetown close to the Cape Sierra Hotel.

Access :

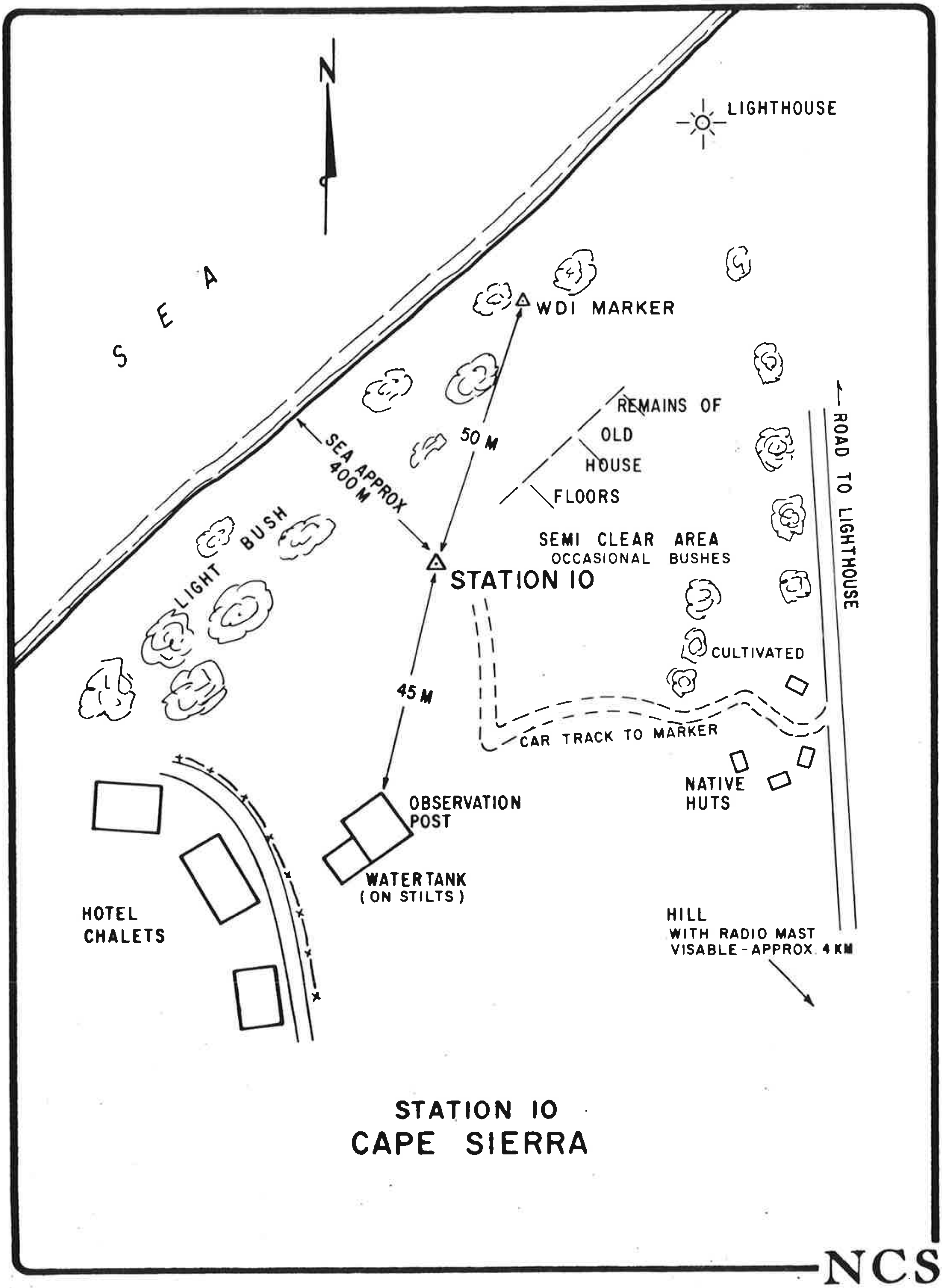
About 50 meters before the Cape Sierra Hotel a track leads off to the right towards the lighthouse. Turn left at the native huts and the marker lies 200 meters from there.

Marker :

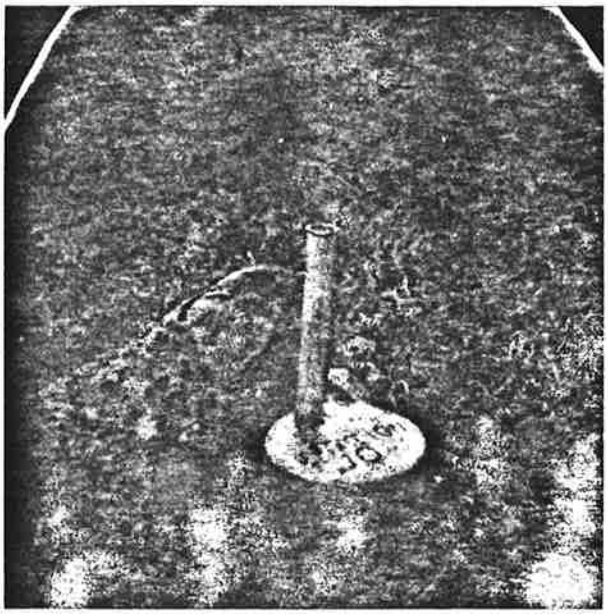
A galvanized steel pipe is set into a 0.5 X 0.5 meter round cement block inscribed "Station 10".

General :

Some blockage from the bush but a 30 foot antenna should be adequate for horizontal navigation.


N
LIGHTHOUSE
SEA
WDI MARKER
REMAINS OF
OLD
HOUSE
FLOORS
50 M
SEA APPROX 400 M
ROAD TO LIGHTHOUSE
LIGHT BUSH
SEMI CLEAR AREA
OCCASIONAL BUSHES
STATION 10
CULTIVATED
45 M
CAR TRACK TO MARKER
NATIVE
HUTS
OBSERVATION
POST
WATERTANK
(ON STILTS)
HOTEL
CHALETS
HILL
WITH RADIO MAST
VISABLE - APPROX 4 KM
STATION 10
CAPE SIERRA

NCS



STATION 10 - CAPE SIERRA

STATION INFORMATION

Station Name	:	Mondo
Station Number	:	11
Dates Occupied (Mo/Day/Yr)	:	06/28/80 to 07/05/80

Eccentricity (Monument to Antenna)

Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.72 Meters

Station Latitude	:	08 Deg 40 Min 45.962 Sec N
Longitude	:	13 Deg 14 Min 39.432 Sec W
Height	:	61.30 meters
Northing	:	959,858.08 meters
Easting	:	693,173.33 meters
Antenna Latitude	:	08 Deg 40 Min 45.962 Sec N
Longitude	:	13 Deg 14 Min 39.432 Sec W
Height	:	63.02 meters
Northing	:	959,858.08 meters
Easting	:	693,173.33 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Nearby Geodetic Monument :

Secondary trigonometrical point is TEL 1 DOS 1959. Identical with Station 11. Coordinates supplied by Land Surveys office in Freetown.

Latitude	:	08 Deg 40 Min 45.7487 Sec N
Longitude	:	13 Deg 14 Min 38.1042 Sec W
Northing	:	959,764.6267 meters
Easting	:	693,217.6548 meters
Height	:	82 feet
UTM	:	Zone 28
Semi-Major Axis	:	6,378,249.145 meters

Site Description :

On a small point (no name), opposite a small island named Leopard Island, cleared of vegetation to southward, but close to palm trees northward.

Location :

On a point of land north of Freetown, on the coast opposite Leopard Island.

Access :

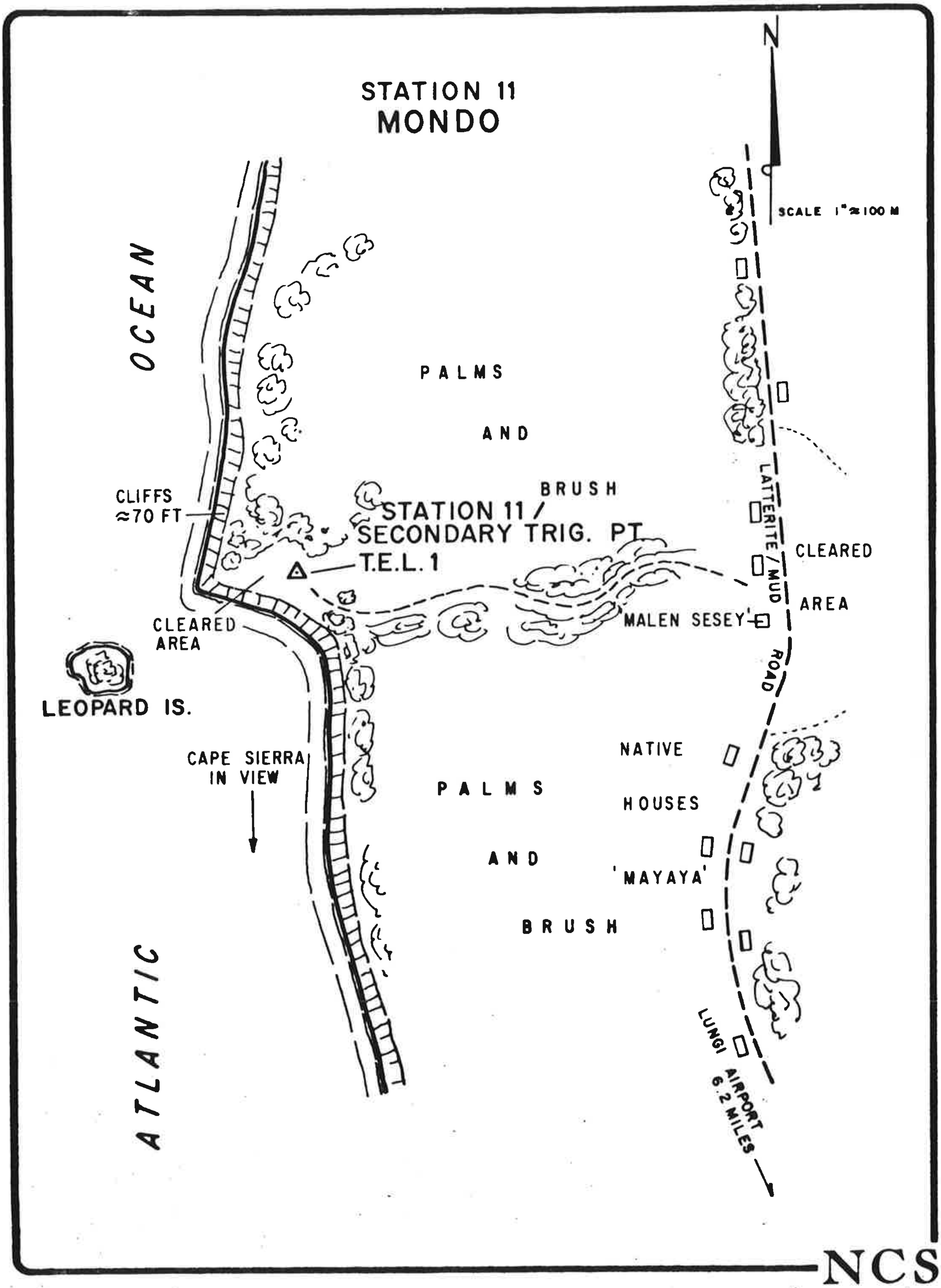
Cross on the ferry which goes from Freetown to the Lungi Airport Road. From the ferry drop, drive 9.1 miles to Lungi Airport Access Road. Continue on Northward Coast Road for 6.2 miles to Mayaya village. Take a guide.

Marker :

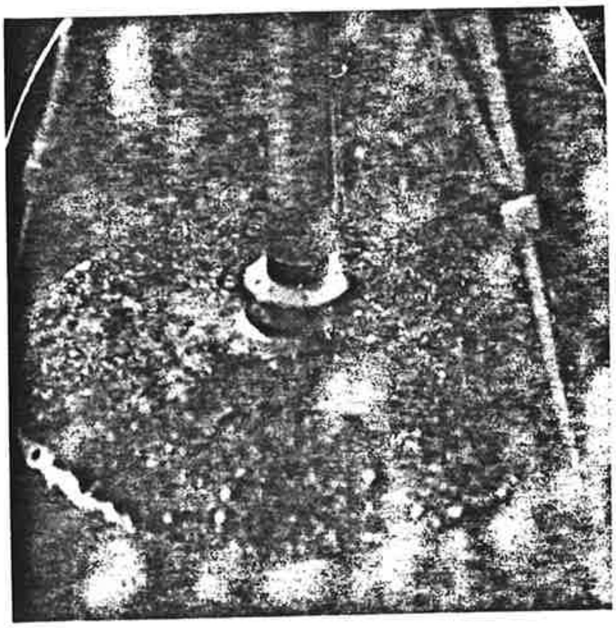
A secondary trigonometrical marker 5 feet high. The marker is round and 1 1/2 feet in diameter, unpainted cement inscribed "Tel 1 D.O.S. 1959".

General :

At Mayaya village, contact Area Chief, Mr. Pa-Alimami Lahie-Mansaray, who will provide guide (Mr. Malen Sesey recommended). The area is clear and minimum antenna height is required for horizontal navigation.


STATION 11
MONDO
N
SCALE 1" ≈ 100 M
OCEAN
ATLANTIC
PALMS
AND
BRUSH
STATION 11 / SECONDARY TRIG. PT
T.E.L. 1
CLIFFS ≈70 FT
CLEARED AREA
LEOPARD IS.
CAPE SIERRA IN VIEW
LATTERITE / MUD ROAD
CLEARED AREA
MALEN SESEY
NATIVE HOUSES 'MAYAYA'
PALMS AND BRUSH
LUNGI AIRPORT 6.2 MILES

NCS



STATION 11 - MONDO
Cement trig station point, "TEL 1 D.O.S. 1959"

STATION INFORMATION

Station Name	:	Kortiman
Station Number	:	12
Dates Occupied (Mo/Day/Yr)	:	07/25/80 to 07/28/80
Eccentricity (Monument to Antenna)		
Horizontal	:	N/A
Bearing	:	N/A
Vertical (up +)	:	1.10 Meters
Station Latitude	:	08 Deg 54 Min 16.577 Sec N
Longitude	:	13 Deg 14 Min 20.811 Sec W
Height	:	39.36 meters
Northing	:	984,765.99 meters
Easting	:	693,625.58 meters
Antenna Latitude	:	08 Deg 54 Min 16.577 Sec N
Longitude	:	13 Deg 14 Min 20.811 Sec W
Height	:	40.46 meters
Northing	:	984,765.99 meters
Easting	:	693,625.58 meters
Spheroid Name	:	WGS-72
Datum	:	Geocentric
Projection	:	Universal Transverse Mercator
Central Meridian	:	15 degrees

Source of Coordinates :

GEODOP processing of satellite data in free adjustment.

Site Description :

The site is situated on a very low flat sand beach which is by a very low mud sea bed. A village surrounds the marker area which would probably have to be abandoned in one to two years due to sea enroachment.

Location :

The site is located on the most westerly point of the island of Kortimaw, 28 miles north of Freetown at the mouth of the Great Scarcies River.

Access :

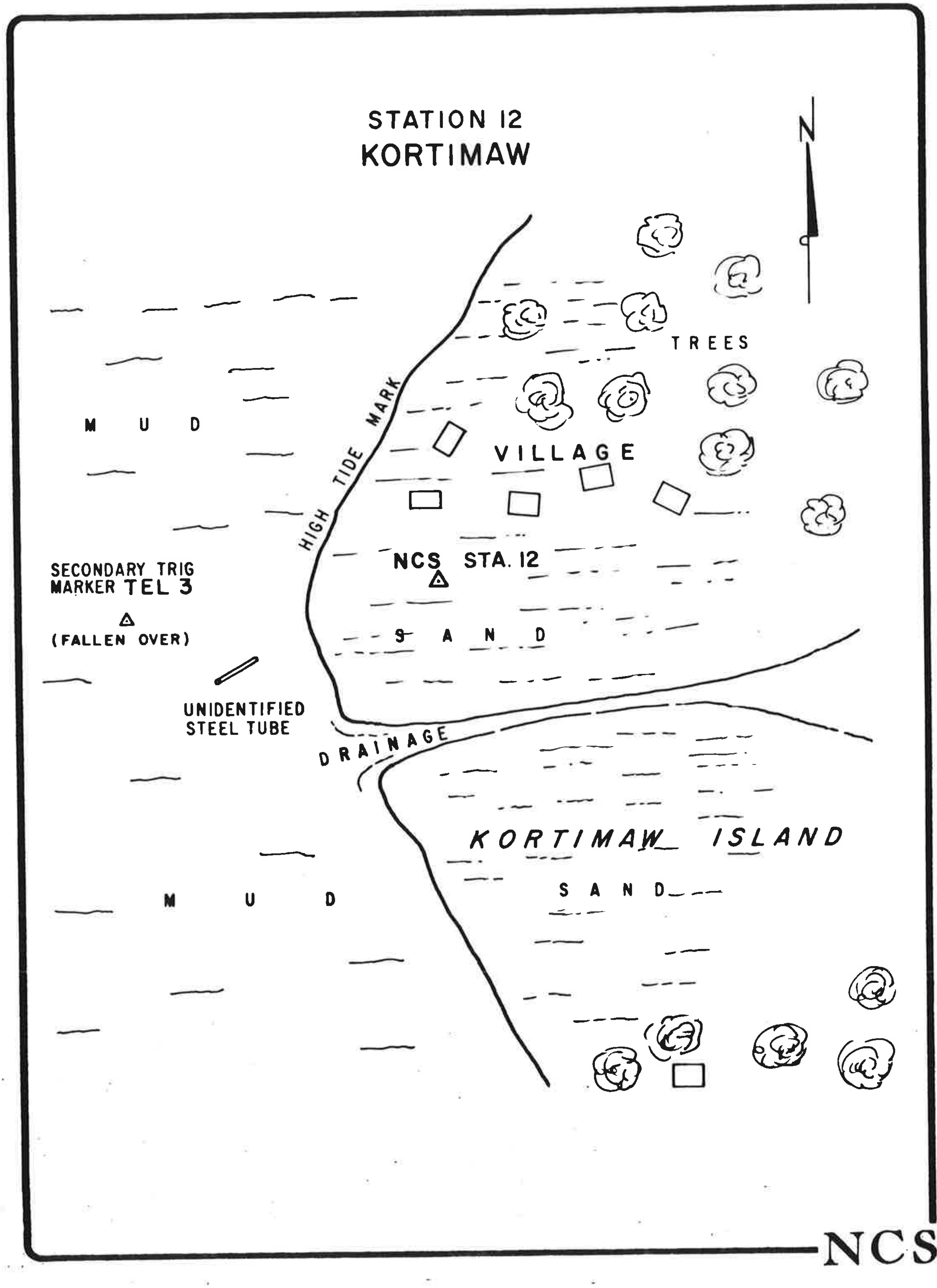
Take Land or Range Rover to Port Loko, Mange and then Mambolo. Hire a boat on the Great Scarcies River to Kortimaw Island. The easiest access is via helicopter.

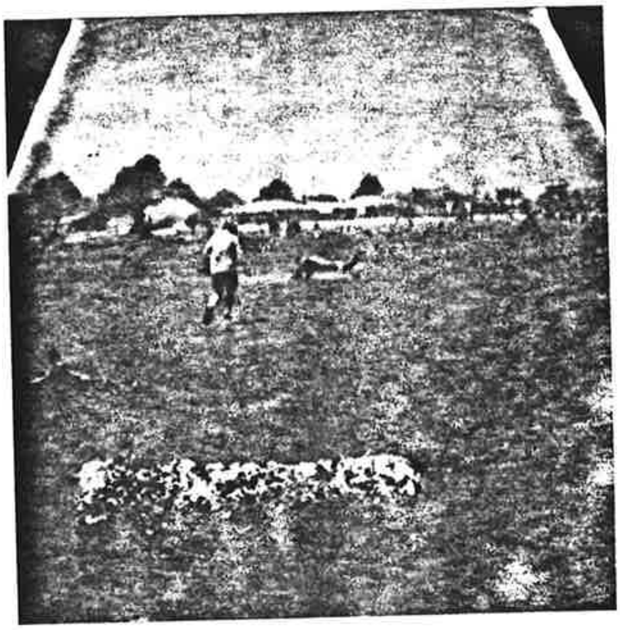
Marker :

A galvanized steel pipe is set into a 0.5 X 0.5 meter round cement block inscribed "Station 12".

General :

It is believed that the TEL 3 marker has been rolled by sea action.


STATION 12
KORTIMAW
N
TREES
MUD
HIGH TIDE MARK
VILLAGE
NCS STA. 12
SECONDARY TRIG MARKER TEL 3
(FALLEN OVER)
SAND
UNIDENTIFIED STEEL TUBE
DRAINAGE
KORTIMAW ISLAND
SAND
MUD
NCS



STATION 12 - KORIMAW
(Destroyed TEL 3 monument
in the foreground.)

SECTION V

INTRODUCTION TO GEODOP

INTRODUCTION TO GEODOP

GEODOP is both a collective term describing a family of satellite reduction FORTRAN programs, developed initially for the CDC 6400 computer, and the name of the family's principal member. This GEODOP family of programs is currently installed for processing on commercially accessible CDC Cyber 175 computing facilities. GEODOP reduces raw doppler and broadcast ephemeral data of the Navy Navigation Satellite System and computes geocentric observing station positions. Optimal results are obtained by maintaining professional standards of data collection, observing a coordinated pattern of site occupation maximizing common data, and by assiduously recording barometric pressures and wet and dry bulb temperatures.

GEODOP computation is a multi-stage process, a flow chart of which is included. Steps in this process are as follows:

<u>Transcription</u>

Raw satellite data is transcribed in EBCDIC code on 9-track tape on a JMR-CR/Pertec 6840 system. Output data tapes are entered into the computer facility library.

<u>Decoding</u>

These "stranger" tapes are accessed and the data decoded is stored on disk in an acceptable CDC format.

<u>Majority Voting</u>

Verified binary files of raw data are "majority voted" by accepting as correct the most commonly occuring redundant digits in the satellite message. Remaining are the satellites orbital parameters and the measured doppler counts in a format acceptable to PREDOP.

<u>PREDOP</u>

PREDOP accesses that section of the formatted majority voted data collected at a particular site and then for each pass does a first order ionspheric refraction correction. The satellite orbit is computed and the doppler counts are compared to theoretical values and edited appropriately. Meteorological data can be input at this stage.

GEODOP

GEODOP in the single station option inputs the PREDOP results plus estimated station position in Cartesian coordinates, receiver time delay, frequency offset, oscillator drift and a receiver weighting factor. Computed are station position and pertaining statistics and, on a pass by pass basis, inputs of receiver delay time, frequency offset and oscillator drift are refined.

Tape 7

"Tape 7" is the disk storage permanent file name of a combined PREDOP/GEODOP run. Previous single station PREDOP and GEODOP "trial runs" have isolated and eliminated all glitches. Input parameters are refined and receiver weighting factors have been adjusted on the basis of program statistics. A final combined PREDOP/GEODOP single station run is cataloged on disk as "Tape 7".

MERGE

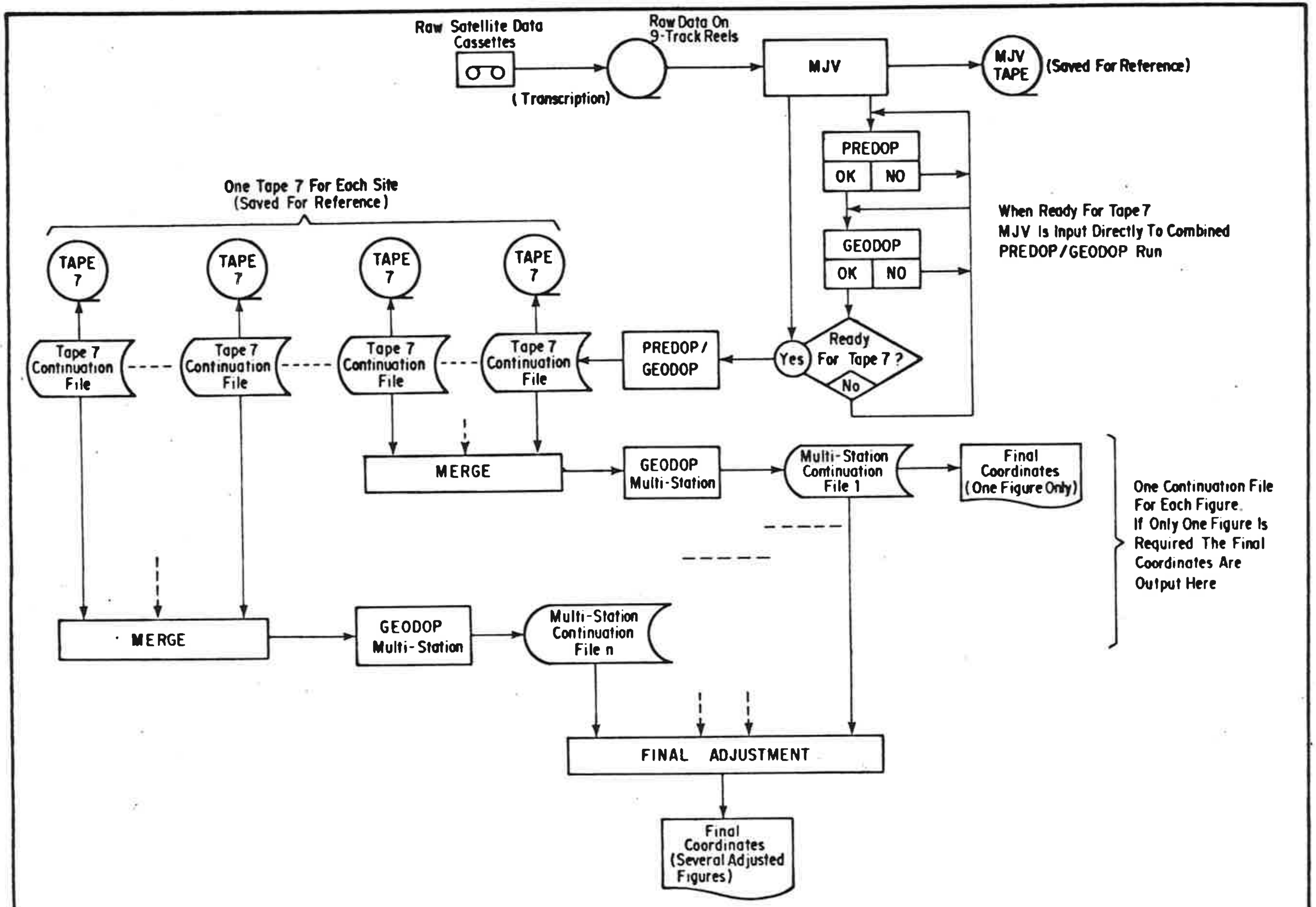
MERGE chronologically combines the Tape 7 output files in a single pass by pass file.

GEODOP Multi-Station

GEODOP Multi-Station is GEODOP in an option mode accepting up to 15 stations for simultaneous processing. This is the program designed to yield the most reliable positions for groups of stations occupied simultaneously and to give reliable variance covariance estimates. A phase adjustment approach is employed whereby each pass is added to the cumulative solution of all preceeding passes after surviving statistical rejection tests.

Final Adjustment

This multi-purpose adjustment program is used in combining more than one multi-station solution. Input coordinates and variance-covariance matricies for two or several "figures" (GEODOP Multi-Station solutions) are combined into a single net of adjusted coordinates with one complete variance- covariance matrix. Adjustment may be free or constrained; scale, rotation and shift factors may be applied. Chord distances between stations are also output.



GEODOP PROCESSING FLOWCHART

NCS

PRINTOUT HIGHLIGHTS

MAJORITY VOTED SECTION

This sections contains the majority vote run listing pass header information as transcribed to 9-track and the full listing run containing satellite parameters, doppler counts and sequential line numbers. These line numbers are used to extract a particular site for later programs. The signal status editing option is noted on the first page.

PREDOP SECTION

Delete numbers refer to data records excluded. Most options noted are self-explanatory. Ones (1s) in the doppler string indicate dopplers used; passes rejected are boldly noted. A frequency offset plot is included. There is one PREDOP run per station.

GEODOP SECTION

GEODOP options are noted on the first two pages of each station's run. Satellites are listed by pass and are clearly annotated. Meteorological data are default values at this stage. Positions with pertaining statistics and a pass summary are given.

TAPE 7 SECTION

These are clearly combined PREDOP/GEODOP runs with improved inputs. Meteorological data is also input.

MERGE SECTION

In MERGE commonality of satellite data is indicated in the station listing at each pass.

GEODOP MULTI-STATION SECTION

Doppler by doppler commonality is displayed in the individual pass reports. Figure results are given at the middle of the multi-station printout, after the pass by pass reports and before the station summaries and covergence graphs.

FINAL ADJUSTMENT

Specified program options are noted on the first few pages of printout. Input figures in Cartesian coordinates are noted under "Residuals" and these are followed by the adjusted results in Cartesian coordinates. The adjusted geographical coordinates follow the inter-station chord distances and are followed by the complete variance-covariance matrix. Eastern Hemisphere longitudes are reported as the explement of the conventional longitude.

SECTION VI

GEODOP FINAL ADJUSTMENT
FREE AND FIXED

FINAL ADJUSTMENT - FREE

```
NO.OF STATIONS     =   12
NO.FREE STATIONS   =   12
NO.CORR.STATIONS   =   12

REQUIRED  CORE    = 13374 OR 101136 IN OCTAL

PARAMETERS CHOSEN FROM CONTROL CARD

COL 25 SOLVE TRANSFORMATION PARAMETERS YES
COL 30 SUPRESS NORMALS                 YES
COL 35 SUPRESS COVARIENCE MATRIX       YES
COL 40 TO SUPRESS INTERSTATION LENGTHS NO
COL 45 ARBITRARY ORIGIN SHIFT          NO
COL 50 COMPUTE LATS AND LONGS          YES
COL 55 PUNCH 3D COORD. AND COV MATRIX  NO
COL 60 WRITE ON TAPE1 2D COORD. AND COV
       MATRIX IN (.001) ARC SECONDS SQ.YES
COL 65 COMPUTE ERROR ELLIPSOIDS        NO

COL 70 APRIORI VARIANCE FACTOR         1.0
COL 75 GANETS CODE 4 APP. COORDINATES  NO
COL 80 TO ADD DOPPLER GANET FIXED STA  NO
```

GEODETIC SURVEY   DATE= 03/09/80

1980 NGS INTL SIERRA LEONE PROJECT FOR MOBIL EXPLORATION

NOTE-ELLIPSOID PARAMETERS   WGS72   A =6378135.0000   F = 298.2600000

APPROXIMATE STATION COORDINATES

10	0.0000	0.0000	0.0000
21 SS01	0.0000	0.0000	0.0000
21 SS02	0.0000	0.0000	0.0000
21 SS03	0.0000	0.0000	0.0000
21 SS04	0.0000	0.0000	0.0000
21 SS05	0.0000	0.0000	0.0000
21 SS06	0.0000	0.0000	0.0000
21 SS07	0.0000	0.0000	0.0000
21 SS08	0.0000	0.0000	0.0000
21 SS9A	0.0000	0.0000	0.0000
21 SS10	0.0000	0.0000	0.0000
21 SS11	0.0000	0.0000	0.0000
21 SS12	0.0000	0.0000	0.0000
40	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000

3-D DOPPLER BINARY FILE
VAR/COVAR MATRIX MULTIPLIED BY SCALAR--- 1.00

POSITION EQUATIONS FROM FILE - BROADCAST   WITH PASSES   212
LOCK IN TIME   144 15 2.0   LOCK OUT TIME   165 15 58.0

SOLVE FOR TRANSFORMATION PARAMETERS

60	0.0000	0.0000	0.0000	1.0000
61 SS9A	6147899.4988	-1437926.5546	900806.0255	
61 SS06	6174467.8072	-1374185.4182	814992.3808	
61 SS07	6162039.6372	-1417425.8108	834866.1682	
61 SS8A	6156846.0393	-1416967.2580	872633.9406	
61 SS10	6139537.9452	-1450965.6700	936062.7181	
62	0.0000	0.0000	0.0000	

WEIGHT COEFFICIENT MATRIX WITH POSITION VARIANCE OF   1.00000 ADDED

3-D DOPPLER BINARY FILE
VAR/COVAR MATRIX MULTIPLIED BY SCALAR--- 1.00

POSITION EQUATIONS FROM FILE - BROADCAST   WITH PASSES   378
LOCK IN TIME [illegible]   LOCK OUT TIME [illegible]

60		0.0000	0.0000	0.0000	1.0000
61	8894	6147901.2205	-1437927.1450	900806.8655	
61	8801	6203991.3992	-1265447.6765	765706.8856	
61	8802	6197232.9107	-1288378.4907	781944.6036	
61	8803	6192863.9937	-1304300.4412	790054.9147	
61	8804	[illegible]	[illegible]	[illegible]	
61	8805	6180749.7439	-1349606.6115	808486.8102	
61	8811	6137920.5107	-1444642.5370	956138.3118	
61	8812	6134521.8270	-1443211.5485	980744.3491	
62		0.0000	0.0000	0.0000	

WEIGHT COEFFICIENT MATRIX WITH POSITION VARIANCE OF 1.00000 ADDED

81 X-SHIFT	0.0000	0.0000	0.0000	.0001
82 Y-SHIFT	0.0000	0.0000	0.0000	.0001
83 Z-SHIFT	0.0000	0.0000	0.0000	.0001
84 SCALE	0.0000	0.0000	0.0000	.0001
85 KAPPA	0.0000	0.0000	0.0000	.0001
86 PHI	0.0000	0.0000	0.0000	.0001
87 OMEGA	0.0000	0.0000	0.0000	0.0000

SOLUTION

.620399E+07	-.126545E+07	.765706E+06	.619723E+07	-.128838E+07	.781944E+06
.619286E+07	-.130430E+07	.790855E+06	.618743E+07	-.132472E+07	.798580E+06
.618075E+07	-.134961E+07	.808486E+06	.617447E+07	-.137419E+07	.814993E+06
.616203E+07	-.141733E+07	.834867E+06	.615685E+07	-.141697E+07	.872634E+06
.614790E+07	-.143793E+07	.900806E+06	.613954E+07	-.145097E+07	.936063E+06
.613792E+07	-.144464E+07	.956138E+06	.613432E+07	-.144321E+07	.980746E+06
.394745E-12	-.869304E-13	.770494E-13	.258993E-11	-.149602E-12	.632216E-12
.145883E-12					

RESIDUALS

STATION	X COORD	RESID	Y COORD	RESID	Z COORD	RESID
899F	6147899.499	.876	-1437926.997	-.305	900806.825	.449
8806	6174467.807	.865	-1374185.418	-.312	814992.381	.446
8807	6162029.637	.868	-1417325.811	-.307	834866.168	.447
880A	6156846.030	.872	-1416967.258	-.303	872633.941	.446
8810	6139537.945	.872	-1450965.670	-.301	936062.718	.447

STATION	X COORD	RESID	Y COORD	RESID	Z COORD	RESID
899A	6147901.221	-.846	-1437927.145	.285	900806.865	-.391
8801	6203991.399	-.840	-1265447.677	.296	765706.886	-.389
8802	6197232.911	-.840	-1288378.491	.295	781944.604	-.389
8803	6192863.994	-.843	-1304300.441	.292	790054.915	-.389
8804	6187428.564	-.844	-1324723.294	.290	798580.354	-.389
8805	6180749.794	-.842	-1349606.611	.292	808486.810	-.389
8811	6137920.511	-.844	-1444642.537	.281	956138.312	-.390
8812	6134323.827	-.842	-1443211.549	.286	980746.349	-.391

S. D. OF UNIT WT.= .766 DEGREES OF FREEDOM= 3.

ADJUSTED COORDS. AND S.D.

	X(COORD)	S.D.	Y(COORD)	S.D.	Z(COORD)	S.D.
8801	6203990.5590	.8169	-1265487.3808	.9219	765706.4961	1.0569
8802	6197252.0764	.8084	-1288378.1954	.8834	781944.2142	1.0433
8803	6192863.1512	.8539	-1304300.1491	.9402	790054.5259	1.0689
8804	6187427.7202	.7988	-1324723.0033	.8934	798579.9650	1.0488
8805	6180709.9919	.8205	-1349606.3193	.9325	808486.4310	1.0626
8806	6174468.6719	.7866	-1374185.7304	.8782	814992.8272	1.0433
8807	6162030.5054	.7890	-1417326.1180	.8826	834866.6157	1.0471
8808	6156806.9114	.7848	-1416967.5608	.8572	872634.3866	1.0462
8809	6147900.3744	.7535	-1437926.8600	.8051	900806.4746	1.0203
8810	6139538.8169	.7707	-1450965.9706	.8350	936063.1650	1.0382
8811	6137949.6870	.7784	-1444642.2556	.8645	956137.9223	1.0447
8812	6134322.9953	.8310	-1443211.2627	.9239	980745.9584	1.0643

TRANSFORMATION PARAMETERS

SCALE =	0.0000	PPM	S.D.=	.0001 PPM
OMEGA =	.0000	SEC.	S.D.=	.0001 SEC.
PHI =	.0000	SEC.	S.D.=	.0001 SEC.
KAPPA =	-.0000	SEC.	S.D.=	.0001 SEC.
X SFT.=	.0000	METRE	S.D.=	.0001 METRE
Y SFT.=	-.0000	METRE	S.D.=	.0001 METRE
Z SFT.=	.0000	METRE	S.D.=	.0001 METRE

LENGTH S.D. DATE=

SS01	SS02	S.D.=	.5360	LENGTH=	28899.1856
SS01	SS03	S.D.=	.6273	LENGTH=	47182.4479
SS01	SS04	S.D.=	.5676	LENGTH=	69775.2968
SS01	SS05	S.D.=	.6346	LENGTH=	97226.6608
SS01	SS06	S.D.=	.5694	LENGTH=	122982.5719
SS01	SS07	S.D.=	.5717	LENGTH=	172078.2366
SS01	SS8A	S.D.=	.5209	LENGTH=	191349.0588
SS01	SS9A	S.D.=	.4034	LENGTH=	226157.6526
SS01	SS10	S.D.=	.4631	LENGTH=	259985.7092
SS01	SS11	S.D.=	.4747	LENGTH=	269704.0862
SS01	SS12	S.D.=	.5398	LENGTH=	287568.3205
SS02	SS03	S.D.=	.6005	LENGTH=	18394.9237
SS02	SS04	S.D.=	.5299	LENGTH=	41156.0268
SS02	SS05	S.D.=	.5996	LENGTH=	68739.1208
SS02	SS06	S.D.=	.5250	LENGTH=	94727.5893
SS02	SS07	S.D.=	.5249	LENGTH=	143761.9474
SS02	SS8A	S.D.=	.4730	LENGTH=	162452.7418
SS02	SS9A	S.D.=	.3016	LENGTH=	197298.3939
SS02	SS10	S.D.=	.4122	LENGTH=	231335.1403
SS02	SS11	S.D.=	.4282	LENGTH=	241412.2317
SS02	SS12	S.D.=	.4997	LENGTH=	259717.0868
SS03	SS04	S.D.=	.6214	LENGTH=	22788.5935
SS03	SS05	S.D.=	.6817	LENGTH=	50389.8685
SS03	SS06	S.D.=	.6177	LENGTH=	76447.8267
SS03	SS07	S.D.=	.6153	LENGTH=	125433.8276
SS03	SS8A	S.D.=	.5578	LENGTH=	144258.6170
SS03	SS9A	S.D.=	.4496	LENGTH=	179286.7628
SS03	SS10	S.D.=	.4992	LENGTH=	213712.1207
SS03	SS11	S.D.=	.5065	LENGTH=	224273.0208

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SS04	SS05	S.D.=	.6140	LENGTH=	27602.9690
SS04	SS06	S.D.=	.5420	LENGTH=	53701.7723
SS04	SS07	S.D.=	.5380	LENGTH=	142450.2626
SS04	SS8A	S.D.=	.4729	LENGTH=	122181.4291
SS04	SS9A	S.D.=	.3463	LENGTH=	157568.3455
SS04	SS10	S.D.=	.4111	LENGTH=	192697.3362
SS04	SS11	S.D.=	.4226	LENGTH=	204098.4672
SS04	SS12	S.D.=	.4884	LENGTH=	223705.2294
SS05	SS06	S.D.=	.6173	LENGTH=	26190.1138
SS05	SS07	S.D.=	.6063	LENGTH=	75048.4123
SS05	SS8A	S.D.=	.5209	LENGTH=	96040.6346
SS05	SS9A	S.D.=	.4142	LENGTH=	131918.6718
SS05	SS10	S.D.=	.4621	LENGTH=	168071.0434
SS05	SS11	S.D.=	.4587	LENGTH=	180740.5278
SS05	SS12	S.D.=	.5167	LENGTH=	201471.0882
SS06	SS07	S.D.=	.5141	LENGTH=	49099.5774
SS06	SS8A	S.D.=	.3940	LENGTH=	73914.5508
SS06	SS9A	S.D.=	.3971	LENGTH=	110148.9361
SS06	SS10	S.D.=	.3382	LENGTH=	147557.8760
SS06	SS11	S.D.=	.3758	LENGTH=	161931.7435
SS06	SS12	S.D.=	.4376	LENGTH=	183984.5123
SS07	SS8A	S.D.=	.3463	LENGTH=	38123.5193
SS07	SS9A	S.D.=	.2680	LENGTH=	70513.2340
SS07	SS10	S.D.=	.3019	LENGTH=	108987.4182
SS07	SS11	S.D.=	.3547	LENGTH=	126626.3546
SS07	SS12	S.D.=	.4118	LENGTH=	150726.6732
SS8A	SS9A	S.D.=	.2871	LENGTH=	34235.3321
SS8A	SS10	S.D.=	.2285	LENGTH=	74018.0514
SS8A	SS11	S.D.=	.3550	LENGTH=	89983.1639
SS8A	SS12	S.D.=	.4119	LENGTH=	113508.4627
SS9A	SS10	S.D.=	.2126	LENGTH=	38509.3270
SS9A	SS11	S.D.=	.2392	LENGTH=	56624.0245

SS10	SS11	S.D.=	.3176	LENGTH=	21109.4030
SS10	SS12	S.D.=	.3694	LENGTH=	45649.6706

LATITUDES, LONGITUDES AND HEIGHTS				STANDARD DEVIATIONS (METRES)		
A= 6378135.000	B= 6356750.520			LAT	LONG	HT
SS01	6 56 29.05215	11 31 43.14872	39.795	1.061	.926	.807
SS02	7 5 21.59820	11 44 39.32844	43.515	1.048	.890	.786
SS03	7 9 47.66579	11 53 36.37462	42.300	1.074	.948	.839
SS04	7 14 27.38117	12 5 4.33147	45.046	1.053	.898	.768
SS05	7 19 52.48963	12 10 3.23744	44.444	1.067	.843	.803
SS06	7 23 26.04770	12 32 49.96814	41.816	1.050	.885	.771
SS07	7 34 18.52698	12 57 11.83119	41.300	1.053	.888	.775
SS08A	7 54 59.21145	12 57 38.35798	45.282	1.050	.864	.772
SS9A	8 10 25.32883	13 9 51.18223	49.198	1.026	.809	.741
SS10	8 29 45.14515	13 17 48.56104	58.985	1.042	.841	.759
SS11	8 40 45.96199	13 14 39.43188	63.017	1.049	.869	.766
SS12	8 54 16.57665	13 10 20.81053	40.463	1.071	.938	.807

2D VAR/COVAR MATRIX IN (.001) ARC SECONDS SQ.

.11939329E+04	-.69557309E+01	.11120233E+04	-.60012724E+01	.11118328E+04	.10703427E+01
.11134731E+04	.80232079E+01	.11128263E+04	-.11770490E+01	.11125487E+04	-.10891976E+02
.11122171E+04	-.70687612E+01	.11110357E+04	.10877236E+02	.11154357E+04	-.16695909E+01
.11120271E+04	-.37047631E+00	.11123240E+04	.50059312E+01	.11141374E+04	-.10420218E+02
-.69557309E+01	.90936442E+03	-.10293683E+02	.68219476E+03	-.10459478E+02	.68011459E+03
-.10472976E+02	.68095428E+03	-.96819932E+01	.68095246E+03	-.91577998E+01	.67543345E+03
-.90052392E+01	.67822019E+03	-.89430189E+01	.67075377E+03	-.83967381E+01	.68711514E+03
-.76455245E+01	.67387514E+03	-.81943671E+01	.68085905E+03	-.76998779E+01	.68353288E+03
.11124233E+04	-.10293683E+02	.11642326E+04	-.90352047E+01	.11089164E+04	.11788706E+01
.11105440E+04	.80712822E+01	.11099075E+04	-.10653100E+01	.11096242E+04	-.10708579E+02
.11092962E+04	-.69081687E+01	.11081266E+04	.10990480E+02	.11125186E+04	-.15289523E+01
.11091262E+04	-.23998529E+00	.11094401E+04	.51056359E+01	.11112498E+04	-.10209021E+02
-.60012724E+01	.68219476E+03	-.90352047E+01	.84138616E+03	-.60407082E+01	.68245579E+03
-.60453871E+01	.68343491E+03	-.52473802E+01	.68331283E+03	-.47055662E+01	.67795102E+03
-.45586648E+01	.68078811E+03	-.45167234E+01	.67336302E+03	-.39569891E+01	.68975275E+03
-.32293110E+01	.67647451E+03	-.38196944E+01	.68334202E+03	-.32859942E+01	.68587578E+03
.11118328E+04	-.10459478E+02	.11089164E+04	-.60407082E+01	.12223467E+04	-.57509931E+00
.11099749E+04	.78272522E+01	.11093304E+04	-.12928153E+01	.11090383E+04	-.11083441E+02
.11087132E+04	-.73002818E+01	.11075530E+04	.10594572E+02	.11119459E+04	-.19369019E+01
.11085619E+04	-.64493322E+00	.11088868E+04	.47383410E+01	.11106799E+04	-.10551438E+02
.10703427E+01	.68011459E+03	.11788706E+01	.68245579E+03	-.57509931E+00	.95444096E+03
.48891007E+00	.68178128E+03	.17712819E+01	.68149810E+03	.23652351E+01	.67619561E+03
.25040419E+01	.67907785E+03	.25203029E+01	.67178196E+03	.30992578E+01	.68807075E+03
.37889916E+01	.67484150E+03	.31556833E+01	.68201184E+03	.37300845E+01	.68415563E+03
.11134731E+04	-.10472976E+02	.11105440E+04	-.60453871E+01	.11099749E+04	.98891007E+00
.11788907E+04	.82231132E+01	.11109671E+04	.12852201E+01	[illegible]	[illegible]

.80232079E+01	.68095428E+03	.88712822E+01	.68343491E+03	.78272522E+01	.68178128E+03
.82221132E+01	.85672099E+03	.86544881E+01	.68261041E+03	.92839314E+01	.67743684E+03
.94159939E+01	.68037303E+03	.94090278E+01	.67317179E+03	.10010017E+02	.68943124E+03
.10667132E+02	.67619125E+03	.99831177E+01	.68339111E+03	.10606920E+02	.68525225E+03
.11128263E+04	-.96819932E+01	.11099075E+04	-.52473802E+01	.11093304E+04	.17712819E+01
[illegible]	[illegible]	[illegible]	-.20557549E+01	.11100450E+04	-.10246616E+02
.11097233E+04	-.64744569E+01	.11085738E+04	.11429479E+02	.11129762E+04	-.11054710E+01
.11095993E+04	.16611797E+00	.11115004E+04	.54413220E+01	.11117314E+04	-.97681302E+01
-.11770490E+01	.68095284E+03	-.10483100E+01	.68334283E+03	-.12928153E+01	.68149810E+03
-.12852201E+01	.68261041E+03	-.20557549E+01	.94442789E+03	.88406241E-01	.67718295E+03
.21772071E+00	.68011300E+03	.20309611E+00	.67276414E+03	.76039249E+00	.68913771E+03
.14313534E+01	.67590115E+03	.59945040E+00	.68835550E+03	.13505031E+01	.68520244E+03
.11125487E+04	-.91577998E+01	.11096242E+04	-.47055662E+01	.11090383E+04	.23652351E+01
.11106808E+04	.92839314E+01	.11100450E+04	.88406241E-01	.11672269E+04	-.71972316E+01
.11094771E+04	-.57795705E+01	.11134828E+04	.11632691E+02	.11127228E+04	-.42577024E+00
.11166995E+04	.19972511E+00	.11096577E+04	.62789837E+01	.11114897E+04	-.91304906E+01
-.10891976E+02	.67543345E+03	-.10708579E+02	.67795102E+03	-.11083441E+02	.67619561E+03
-.11154366E+02	.67743684E+03	-.10246616E+02	.67718295E+03	-.71972316E+01	.63229143E+03
-.93890784E+01	.67789851E+03	-.97947323E+01	.68093558E+03	-.89633726E+01	.68586846E+03
-.88288226E+01	.68771513E+03	-.89996418E+01	.67909829E+03	-.82456816E+01	.68137982E+03
.11122171E+04	-.90052392E+01	.11092962E+04	-.45586648E+01	.11087132E+04	.25040419E+01
.11103574E+04	.94159939E+01	.11097233E+04	.21772071E+00	.11094771E+04	-.93890784E+01
.11759176E+04	-.47372408E+01	.11080332E+04	.12148119E+02	.11124199E+04	-.32768311E+00
.11090727E+04	.92522615E+00	.11093681E+04	.63717736E+01	.11112036E+04	-.90315430E+01
-.70687612E+01	.67822019E+03	-.69081687E+01	.68078811E+03	-.73002818E+01	.67907785E+03
-.73771846E+01	.68037303E+03	-.64744569E+01	.68011300E+03	-.57795705E+01	.67789851E+03
-.47372408E+01	.83881804E+03	-.56822523E+01	.67347842E+03	-.52722033E+01	.68899850E+03
-.46215399E+01	.67659336E+03	-.53805905E+01	.68223240E+03	-.46366027E+01	.68446444E+03
.11110357E+04	-.89430189E+01	.11081266E+04	-.45167234E+01	.11075530E+04	.25203029E+01
.11092024E+04	.64090278E+01	.11085738E+04	.20309611E+00	.11134828E+04	-.97947323E+01
.11080332E+04	-.56822523E+01	.11672175E+04	.12099236E+02	.11113295E+04	-.44813727E+00
.11371319E+04	.39727348E-01	.11083205E+04	.62378543E+01	.11101667E+04	-.91454241E+01
.10877234E+02	.67075377E+03	.10990080E+02	.67336302E+03	.10594572E+02	.67178196E+03
.10546037E+02	.67317179E+03	.11429479E+02	.67276414E+03	.11632691E+02	.68093558E+03
.12148119E+02	.67347842E+03	.12099236E+02	.79621822E+03	.12671468E+02	.68152871E+03
.13096282E+02	.72974777E+03	.12521234E+02	.67494240E+03	.13288593E+02	.67690340E+03
.11154357E+04	-.83967381E+01	.11125186E+04	-.39569891E+01	.11119459E+04	.30992578E+01
.11136053E+04	.10010017E+02	.11129762E+04	.76039249E+00	.11127228E+04	-.89633726E+01
.11124199E+04	-.52722033E+01	.11113295E+04	.12671468E+02	.11157686E+04	.71360091E-01
.11124346E+04	.12940048E+01	.11127635E+04	.67757326E+01	.11146227E+04	-.86652330E+01
-.16695909E+01	.68711514E+03	-.15289523E+01	.68975275E+03	-.19369019E+01	.68807075E+03
-.20131949E+01	.68943124E+03	-.11054710E+01	.68913771E+03	-.42577024E+00	.68586846E+03
-.32768311E+00	.68899850E+03	-.44813727E+00	.68152871E+03	.71360091E-01	.69823210E+03
.66729744E+00	.68487061E+03	-.88512568E-01	.69141503E+03	.66322427E+00	.69359733E+03
.11120271E+04	-.76455245E+01	.11091262E+04	-.32293110E+01	.11085619E+04	.37889916E+01
.11102221E+04	.10667132E+02	.11095993E+04	.14313534E+01	.11166995E+04	-.88288226E+01
.11090727E+04	-.46215399E+01	.11371319E+04	.13096282E+02	.11124346E+04	.66729744E+00
.11507270E+04	.15186021E+01	.11094706E+04	.73392760E+01	.11113352E+04	-.80493814E+01
-.37047631E+00	.67387514E+03	-.23998529E+00	.67647451E+03	-.64493322E+00	.67484150E+03
-.72138547E+00	.67619125E+03	.16611797E+00	.67590115E+03	.19972511E+00	.68771513E+03
.92522615E+00	.67659336E+03	.39727348E-01	.72974777E+03	.12940048E+01	.68487061E+03
.15185021E+01	.75595436E+03	.11149177E+01	.67819520E+03	.18482898E+01	.68031627E+03
.11123240E+04	-.81943671E+01	.11094401E+04	-.38196994E+01	.11088868E+04	.31556833E+01
.11103435E+04	.99831177E+01	.11115004E+04	.59945040E+00	.11096577E+04	-.89996418E+01
.11093681E+04	-.53805905E+01	.11083205E+04	.12521234E+02	.11127635E+04	-.88512568E-01
.11094706E+04	.11149177E+01	.11669582E+04	.70982618E+01	.11116844E+04	-.87363858E+01
.50059312E+01	.68085905E+03	.51056359E+01	.68334202E+03	.47383410E+01	.68201184E+03
.47212323E+01	.68339111E+03	.54413220E+01	.68835550E+03	.62789837E+01	.67909829E+03
.63717736E+01	.68223240E+03	.62378543E+01	.67494240E+03	.67757326E+01	.69141503E+03
.73392760E+01	.67819520E+03	.70982618E+01	.80876264E+03	.72918728E+01	.68722253E+03
.11141374E+04	-.76998779E+01	.11112498E+04	-.32859942E+01	.11106799E+04	.37300845E+01
.11123403E+04	.10606920E+02	.11117314E+04	.13505031E+01	.11114897E+04	-.82456816E+01
.11112036E+04	-.46366027E+01	.11101667E+04	.13288593E+02	.11186227E+04	.66322427E+00
.11113352E+04	.18482898E+01	.11116844E+04	.72918728E+01	.12143728E+04	-.13411378E+02
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FINAL ADJUSTMENT - FIXED

NOTE : Master Sute 9 fixed to results of Final Adjustment Free; positional results for all stations identical to Final Adjustment Free. This exercise merely exhibits relative accuracies, rather than absolute accuracies, in output statistics.

```
NO.OF STATIONS    =   12
NO.FREE STATIONS =    12
NO.CURR.STATIONS =    12

REQUIRED CORE    = 33374 OR 101136 IN OCTAL

PARAMETERS CHOSEN FROM CONTROL CARD

COL 25 SOLVE TRANSFORMATION PARAMETERS YES
COL 30 SUPRESS NORMALS                 YES
COL 35 SUPRESS COVARIENCE MATRIX       YES
COL 40 TO SUPRESS INTERSTATION LENGTHS NO
COL 45 ARBITRARY ORIGIN SHIFT          NO
COL 50 COMPUTE LATS AND LONGS          YES
COL 55 PUNCH 3D COORD. AND COV MATRIX  NO
COL 60 WRITE ON TAPE1 2D COORD. AND COV
       MATRIX IN (.001) ARC SECONDS SQ.YES
COL 65 COMPUTE ERROR ELLIPSOIDS        NO

COL 70 APRIORI VARIANCE FACTOR         1.0
COL 75 GANETS CODE 4 APP. COORDINATES  NO
COL 80 TO ADD DOPPLER GANET FIXED STA  NO
```

GEODETIC SURVEY DATE= 03/../80

1980 NGS INTL SIERRA LEONE PROJECT FOR MOBIL EXPLORATION

NOTE-ELLIPSOID PARAMETERS WGS72 A =6378135.0000 F = 298.2600000

APPROXIMATE STATION COORDINATES

10	0.0000	0.0000	0.0000
21 8801	0.0000	0.0000	0.0000
21 8802	0.0000	0.0000	0.0000
21 8803	0.0000	0.0000	0.0000
21 8804	0.0000	0.0000	0.0000
21 8805	0.0000	0.0000	0.0000
21 8806	0.0000	0.0000	0.0000
21 8807	0.0000	0.0000	0.0000
21 8884	0.0000	0.0000	0.0000
21 889A	0.0000	0.0000	0.0000
21 8810	0.0000	0.0000	0.0000
21 8811	0.0000	0.0000	0.0000
21 8812	0.0000	0.0000	0.0000
40	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000

3-D DOPPLER BINARY FILE
VAR/COVAR MATRIX MULTIPLIED BY SCALAR--- 1.00

POSITION EQUATIONS FROM FILE - BROADCAST WITH PASSES 212
LOCK IN TIME 144 15 2.0 LOCK OUT TIME 165 15 58.0

SOLVE FOR TRANSFORMATION PARAMETERS

60	0.0000	0.0000	0.0000	1.0000
61 889A	6147899.4988	-1437926.5546	900806.0255	
61 8806	6174467.8072	-1374185.4182	814992.3808	
61 8807	6162027.6372	-1417325.8108	834866.1682	
61 888A	6156846.0393	-1414967.2580	872633.9406	
61 8810	6139537.9452	-1450965.6700	936062.7181	
62	0.0000	0.0000	0.0000	

WEIGHT COEFFICIENT MATRIX WITH POSITION VARIANCE OF 1.00000 ADDED

3-D DOPPLER BINARY FILE
VAR/COVAR MATRIX MULTIPLIED BY SCALAR--- 1.00

POSITION EQUATIONS FROM FILE - BROADCAST WITH PASSES 374
LOCK IN TIME 177 4 16.0 LOCK OUT TIME 210 12 40.0

SOLVE FOR TRANSFORMATION PARAMETERS

```
                    0.0000         0.0000         0.0000         1.0000
60
61 SS9A          6147901.2205     37927.1450    900806.8655
61 SS01          6203991.3992  -.265447.6765    765706.8856
61 SS02          6197232.9107  -1288378.4907    781944.6036
61 SS03          6192863.9937  -1304300.4412    790054.9147
61 SS04          6187420.5630  -1324723.2930    798580.3541
61 SS05          6180749.7439  -1349606.6115    808486.8102
61 SS11          6137920.5107  -1444642.5370    956138.3118
61 SS12          6134323.0270  -1443211.5405    980746.3491
62                     0.0000         0.0000         0.0000
        WEIGHT COEFFICIENT MATRIX WITH POSITION VARIANCE OF    1.00000 ADDED
                       0.0000         0.0000         0.0000         0.0000
60
61 SS9A          6147900.3740  -1437926.8600    900806.4750
                       0.0000         0.0000         0.0000
62                     0.0000         0.0000         0.0000          .0001
81 X-SHIFT             0.0000         0.0000         0.0000          .0001
82 Y-SHIFT             0.0000         0.0000         0.0000          .0001
83 Z-SHIFT             0.0000         0.0000         0.0000          .0001
84 SCALE               0.0000         0.0000         0.0000          .0001
85 KAPPA               0.0000         0.0000         0.0000          .0001
86 PHI                 0.0000         0.0000         0.0000          .0001
87 OMEGA               0.0000         0.0000         0.0000         0.0000
99

     SOLUTION
       .620399E+07   -.126545E+07    .765706E+06    .619723E+07   -.128838E+07    .781944E+06

       .619286E+07   -.130430E+07    .790055E+06    .618743E+07   -.132472E+07    .798580E+06

       .618075E+07   -.134961E+07    .808486E+06    .617487E+07   -.137419E+07    .814993E+06

       .616203E+07   -.141733E+07    .834867E+06    .615685E+07   -.141697E+07    .872634E+06

       .614790E+07   -.143793E+07    .900806E+06    .613954E+07   -.145097E+07    .936063E+06

       .613792E+07   -.144464E+07    .956138E+06    .613432E+07   -.144321E+07    .980746E+06

      -.701258E-11    .247373E-13    .301302E-11   -.404750E-10    .481498E-10    .120440E-09

       .211076E-10
```

RESIDUALS

STATION	X COORD	RESID	Y COORD	RESID	Z COORD	RESID
S99A	6147899.499	.875	-1437926.555	-.305	900806.025	.450
S806	6174467.807	.864	-1374185.418	-.312	814992.381	.447
S807	6162029.637	.868	-1417325.811	-.307	834866.168	.448
S808	6156046.630	.873	-1416967.258	-.303	872633.941	.446
S810	6139537.945	.871	-1450965.670	-.301	936062.718	.447

STATION	X COORD	RESID	Y COORD	RESID	Z COORD	RESID
S99A	6147901.221	-.847	-1437927.145	.285	900806.865	-.390
S801	6203991.399	-.841	-1265447.677	.296	765706.886	-.389
S802	6197252.911	-.841	-1288378.491	.295	781944.604	-.389
S803	6192863.994	-.843	-1304300.441	.292	790054.915	-.388
S804	6187428.564	-.844	-1324723.294	.290	798580.354	-.389
S805	6180749.748	-.842	-1349606.611	.292	808486.810	-.389
S811	6137920.511	-.844	-1444642.537	.281	956138.312	-.389
S812	6134323.827	-.842	-1443211.549	.286	980746.349	-.390

STATION	X COORD	RESID	Y COORD	RESID	Z COORD	RESID
S99A	6147900.374	.000	-1437926.860	.000	900806.475	-.000

S. D. OF UNIT WT.= .542 DEGREES OF FREEDOM= 6.

ADJUSTED COORDS. AND S.D.

	X(COORD)	S.D.	Y(COORD)	S.D.	Z(COORD)	S.D.
SS01	6203990.5585	.3256	-1265447.3805	.4659	765706.4965	.2745
~~SS02~~	~~6197232.0499~~	~~.2857~~	~~-1288378.1954~~	~~.3776~~	~~781984.2146~~	~~.2276~~
SS03	6192863.1508	.4100	-1304300.1491	.4986	790054.5262	.3283
SS04	6187427.7198	.2805	-1324723.0033	.4016	798579.9654	.2460
~~SS05~~	~~6180740.9015~~	~~.3401~~	~~-1349606.3193~~	~~.4033~~	~~808486.4214~~	~~.3014~~
SS06	6174468.6715	.2418	-1374185.7304	.3787	814992.8276	.2325
SS07	6162030.5049	.2456	-1417326.1180	.3820	834866.6161	.2501
~~SS08~~	~~6156046.9110~~	~~.2594~~	~~-1416967.5608~~	~~.3380~~	~~872634.3869~~	~~.2385~~
SS9A	6147900.3740	.0100	-1437926.8600	.0100	900806.4750	.0100
SS10	6139538.8164	.2030	-1450965.9706	.2732	936063.1654	.1977
~~SS11~~	~~6137919.6665~~	~~.2177~~	~~-1444642.2556~~	~~.3360~~	~~956137.9226~~	~~.2316~~
SS12	6134322.9449	.3574	-1443211.2627	.4647	980745.9588	.3068

TRANSFORMATION PARAMETERS

```
SCALE =    -.0000  PPM.    S.D.=  .0001 PPM.
OMEGA =     .0000  SEC.    S.D.=  .0001 SEC.
PHI   =     .0000  SEC.    S.D.=  .0001 SEC.
KAPPA =     .0000  SEC.    S.D.=  .0001 SEC.
X SFT.=    -.0000  METRE   S.D.=  .0001 METRE
Y SFT.=     .0000  METRE   S.D.=  .0001 METRE
Z SFT.=     .0000  METRE   S.D.=  .0001 METRE
```

LENGTH S.D.　　　　DATE=

SS01	SS02	S.D.=	.5360	LENGTH=	28899.1856
SS01	SS03	S.D.=	.6271	LENGTH=	47182.4478
SS01	SS04	S.D.=	.5673	LENGTH=	69775.2868
SS01	SS05	S.D.=	.6345	LENGTH=	97226.6608
SS01	SS06	S.D.=	.5694	LENGTH=	122982.5719
SS01	SS07	S.D.=	.5717	LENGTH=	172078.2356
SS01	SS8A	S.D.=	.5205	LENGTH=	191349.0588
SS01	SS9A	S.D.=	.4031	LENGTH=	226157.6526
SS01	SS10	S.D.=	.4619	LENGTH=	259985.7092
SS01	SS11	S.D.=	.4744	LENGTH=	269704.0862
SS01	SS12	S.D.=	.5398	LENGTH=	287568.3205
SS02	SS03	S.D.=	.6005	LENGTH=	18394.9237
SS02	SS04	S.D.=	.5297	LENGTH=	41156.0268
SS02	SS05	S.D.=	.5995	LENGTH=	68739.1208
SS02	SS06	S.D.=	.5249	LENGTH=	94727.5893
SS02	SS07	S.D.=	.5249	LENGTH=	143761.9474
SS02	SS8A	S.D.=	.4726	LENGTH=	162452.7418
SS02	SS9A	S.D.=	.3415	LENGTH=	197298.3939
SS02	SS10	S.D.=	.4120	LENGTH=	231335.1403
SS02	SS11	S.D.=	.4281	LENGTH=	241412.2317
SS02	SS12	S.D.=	.4996	LENGTH=	259717.0868
SS03	SS04	S.D.=	.6214	LENGTH=	22788.5935
SS03	SS05	S.D.=	.6817	LENGTH=	50389.8685
SS03	SS06	S.D.=	.6176	LENGTH=	76447.8267
SS03	SS07	S.D.=	.6153	LENGTH=	125433.8276
SS03	SS8A	S.D.=	.5577	LENGTH=	144258.6170
SS03	SS9A	S.D.=	.4495	LENGTH=	179286.7628
SS03	SS10	S.D.=	.4991	LENGTH=	213712.1207
[illegible]	SS11	S.D.=	[illegible]	LENGTH=	[illegible]

SS04	SS05	S.D.=	.6140	LENGTH=	27602.9690
SS04	SS06	S.D.=	.5417	LENGTH=	53701.7723
SS04	SS07	S.D.=	.5378	LENGTH=	102650.3626
SS04	SS8A	S.D.=	.4728	LENGTH=	122181.4291
SS04	SS9A	S.D.=	.3461	LENGTH=	157568.3455
SS04	SS10	S.D.=	.4110	LENGTH=	142697.3382
SS04	SS11	S.D.=	.4226	LENGTH=	208098.4672
SS04	SS12	S.D.=	.4883	LENGTH=	223705.2294
SS05	SS06	S.D.=	.6173	LENGTH=	26190.1138
SS05	SS07	S.D.=	.6062	LENGTH=	75048.4123
SS05	SS8A	S.D.=	.5208	LENGTH=	96040.6346
SS05	SS9A	S.D.=	.4141	LENGTH=	131918.6718
SS05	SS10	S.D.=	.4620	LENGTH=	168071.0434
SS05	SS11	S.D.=	.4587	LENGTH=	180740.5278
SS05	SS12	S.D.=	.5167	LENGTH=	201471.0882
SS06	SS07	S.D.=	.5140	LENGTH=	49099.5774
SS06	SS8A	S.D.=	.3937	LENGTH=	73914.5508
SS06	SS9A	S.D.=	.3969	LENGTH=	110148.9361
SS06	SS10	S.D.=	.3381	LENGTH=	147557.8760
SS06	SS11	S.D.=	.3757	LENGTH=	161931.7435
SS06	SS12	S.D.=	.4376	LENGTH=	183984.5123
SS07	SS8A	S.D.=	.3463	LENGTH=	38123.5193
SS07	SS9A	S.D.=	.2680	LENGTH=	70513.2340
SS07	SS10	S.D.=	.3418	LENGTH=	108987.4182
SS07	SS11	S.D.=	.3547	LENGTH=	126626.3546
SS07	SS12	S.D.=	.4117	LENGTH=	150726.6732
SS8A	SS9A	S.D.=	.2867	LENGTH=	36235.3321
SS8A	SS10	S.D.=	.2284	LENGTH=	74018.0515
SS8A	SS11	S.D.=	.3550	LENGTH=	89983.1639
SS8A	SS12	S.D.=	.4118	LENGTH=	113508.4627
SS9A	SS10	S.D.=	.2125	LENGTH=	38509.3270

9910	9911	S.D.=	.3176	LENGTH=	21109.4030
9910	9912	S.D.=	.3694	LENGTH=	45649.6706
9911	9913	S.D.=	.3860	LENGTH=	24910.6363

LATITUDES, LONGITUDES AND HEIGHTS

STANDARD DEVIATIONS (METRES)

A= 6378135.000 B= 6356750.520

Station	Latitude	Longitude	Height	LAT	LONG	HT
SS01	6 56 29.05216	11 31 43.14872	34.795	.272	.468	.324
SS02	7 5 21.58821	11 44 39.32862	41.515	.228	.387	.272
SS03	7 9 47.66581	11 53 36.37462	42.300	.328	.510	.346
SS04	7 14 27.38118	12 5 4.33147	45.045	.247	.406	.273
SS05	7 19 52.48965	12 19 3.23711	43.616	.302	.498	.317
SS06	7 23 26.04772	12 32 49.96814	41.816	.233	.386	.230
SS07	7 34 18.52700	12 57 11.83120	41.299	.251	.387	.237
SS08	7 54 59.21117	12 57 38.35799	45.283	.239	.350	.242
SS9A	8 10 25.32884	13 9 51.18223	49.197	.010	.010	.010
SS10	8 29 45.14517	13 17 48.56105	58.985	.198	.281	.192
SS11	8 40 45.96200	13 14 39.43188	63.016	.232	.341	.249
SS12	8 54 16.57666	13 14 20.81053	80.863	.309	.486	.327

20 VAR/COVAR MATRIX IN (.001) ARC SECONDS SQ.

.78692830E+02	.36190631E+01	.11389835E+00	.10003895E+00	.11866671E+00	.62186512E-01
.11971101E+00	.66300090E-01	.11644151E+00	.65813829E-01	.10567891E+00	-.11773894E-02
.10564126E+00	-.79529962E-03	.10551581E+00	.90675606E-03	.10592729E+00	-.27532614E-03
.10557214E+00	-.14532534E-03	.10628042E+00	-.65450349E-01	.97460001E-01	-.36805398E-01
.36190631E+01	.23234615E+03	.74784347E-01	.26941492E+01	.26107867E+00	.24200500E+01
.29827051E+00	.20566206E+01	.16803863E+00	.23590931E+01	-.96021758E-03	.10326626E+00
-.93573808E-03	.10367889E+00	-.91802768E-03	.10254428E+00	-.83057514E-03	.10502882E+00
-.71042642E-03	.10300267E+00	.13178211E+00	.64869396E+00	-.16405831E+00	.10308990E+01
.11389835E+00	.74784347E-01	.54853725E+02	-.31250321E+01	.12907919E+00	.34274749E-02
.11490161E+00	-.30607643E-01	.12380959E+00	.12698752E-01	.10539814E+00	-.11493166E-02
.10536136E+00	-.77059933E-03	.10523785E+00	.92675667E-03	.10564893E+00	-.25289803E-03
.10531613E+00	-.12417968E-03	.12073385E+00	-.85312415E-01	.10956595E+00	.12605089E-01
.10003895E+00	.26941492E+01	-.31250321E+01	.15936848E+03	.22940871E+00	.22137046E+01
.27242594E+00	.19496063E+01	.15038475E+00	.21620358E+01	-.53325068E-03	.10364903E+00
-.50957470E-03	.10406965E+00	-.49523122E-03	.10293769E+00	-.40664665E-03	.10543032E+00
-.28477027E-03	.10339781E+00	.98022907E-01	.48984572E+00	-.16302126E+00	.78758178E+00
.11866671E+00	.26107867E+00	.12907919E+00	.22940871E+00	.11414817E+03	-.13829875E+01
.13848109E+00	.10129137E+00	.13342132E+00	.16077007E+00	.10533959E+00	-.12054979E-02
.10530350E+00	-.82969384E-03	.10518168E+00	.86778749E-03	.10559320E+00	-.31435007E-03
.10526158E+00	-.18495033E-03	.12804611E+00	-.43152279E-01	.98283278E-01	.71606308E-01
.62186512E-01	.24200500E+01	.34274749E-02	.22137046E+01	-.13829875E+01	.27591500E+03
.22212992E+00	.19624903E+01	.93195642E-01	.20621325E+01	.14375551E-03	.10338020E+00
.16620609E-03	.10380753E+00	.17634921E-03	.10269021E+00	.26632007E-03	.10517126E+00
.37792636E-03	.10314683E+00	.59038925E-01	.77796484E+00	-.16409127E+00	.79169077E+00
.11971101E+00	.29827051E+00	.11990161E+00	.27242594E+00	.13848109E+00	.22212992E+00
.64521352E+02	.53061363E+00	.12829776E+00	.22013904E+00	.10549297E+00	-.12148487E-02
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.20560206E+01	-.30807693E-01	.19496063E+01	.10129137E+00	.19624903E+01
.53061363E+00	.17555611E+03	.56004347E-01	.18781421E+01	.80530287E-03	.10356909E+00
.82673075E-03	.10400453E+00	.83313413E-03	.10289619E+00	.92500526E-03	.10537747E+00
.10322400E-02	.10335106E+00	.14525949E-01	.76481876E+00	-.16608263E+00	.58982648E+00
.11644151E+00	.16803863E+00	.12380959E+00	.15038475E+00	.13342132E+00	.93195642E-01
.12024776E+00	.56004347E-01	.96804426E+02	-.14599512E+01	.10543074E+00	-.10762151E-02
.10539583E+00	-.70255364E-03	.10527605E+00	.99590842E-03	.10568919E+00	-.18610136E-03
.10535959E+00	-.59677546E-04	.17004915E+01	-.16672107E+00	.10163247E+00	.38160456E-01
[illegible]	.23590931E+01	.12698752E-01	.21620358E+01	.16077007E+00	.20621325E+01
.22013904E+00	.18781421E+01	-.14599512E+01	.26404312E+03	-.62766981E-04	.10352390E+00
-.41904471E-04	.10396056E+00	-.37571645E-04	.10283718E+00	.49320171E-04	.10533101E+00
.15696240E-03	.10330607E+00	-.12553470E+00	.60715894E+01	-.15687511E+00	.75776030E+00
.10567891E+00	-.96021758E-03	.10539814E+00	-.53325068E-03	.10533959E+00	.14375551E-03
.10549297E+00	.80530287E-03	.10543074E+00	-.62766981E-04	.57547957E+02	.23680757E+01
.11025526E+00	.18509976E-01	.52688538E+01	-.46064603E+00	.10566446E+00	-.81775961E-04
.74539011E+01	-.63067677E+00	.10536118E+00	.55656930E-03	.10553123E+00	-.90850203E-03
-.11773894E-02	.10326626E+00	-.11493166E-02	.10364903E+00	-.12054979E-02	.10338020E+00
-.12140487E-02	.10356909E+00	-.10762151E-02	.10352390E+00	.23680757E+01	.15840093E+03
.52079259E-01	.10890200E+01	-.32550250E+00	.11598037E+02	-.87031280E-03	.10482909E+00
-.54442732E+00	.15122972E+02	-.87017349E-03	.10379588E+00	-.75224545E-03	.10413899E+00
.10564126E+00	-.93573808E-03	.10536136E+00	-.50957470E-03	.10530350E+00	.16620608E-03
.10545748E+00	.82673075E-03	.10539583E+00	-.41904471E-04	.11825526E+00	.52079259E-01
.66875431E+02	.95341553E+00	.12515442E+00	-.47977557E-01	.10563407E+00	-.65720048E-04
.12053785E+00	.39528945E-02	.10533326E+00	.57252614E-03	.10554397E+00	-.89146786E-03
-.79529962E-03	.10367889E+00	-.77059933E-03	.10406965E+00	-.82969384E-03	.10380753E+00
-.84045209E-03	.10400453E+00	-.70255364E-03	.10396056E+00	.18509976E-01	.10890200E+01
.95341553E+00	.15898348E+03	.92501699E-01	.10961432E+01	-.51185025E-03	.10530217E+00
.22349036E-01	.90282196E+00	-.52410245E-03	.10426887E+00	-.40851426E-03	.10460663E+00
.10551581E+00	-.91802768E-03	.10523785E+00	-.49523122E-03	.10518168E+00	.17634921E-03
.10533602E+00	.83313413E-03	.10527605E+00	-.37571645E-04	.52688538E+01	-.32550250E+00
.12515442E+00	.92501699E-01	.60408831E+02	-.54460384E-03	.10552533E+00	-.80708432E-04
.29239663E+02	-.74619669E+00	.10523215E+00	.55551747E-03	.10540496E+00	-.90590216E-03
.90675606E-03	.10254428E+00	.92675667E-03	.10293769E+00	.86778749E-03	.10269021E+00
.86031671E-03	.10289619E+00	.99590842E-03	.10283718E+00	-.46064603E+00	.11598037E+02
-.47977557E-01	.10961432E+01	-.54460384E-03	.13091926E+03	.11913926E-02	.10416080E+00
-.14506574E+00	.61365197E+02	.11752286E-02	.10315158E+00	.12927935E-02	.10345997E+00
.10592729E+00	-.83057514E-03	.10564893E+00	-.40664665E-03	.10559320E+00	.26632007E-03
.10574964E+00	.92500526E-03	.10568919E+00	.49320171E-04	.10566446E+00	-.87031280E-03
.10563407E+00	-.51185025E-03	.10552533E+00	.11913926E-02	.10594475E+00	.15618909E-08
.10562397E+00	.11869673E-03	.10565325E+00	.63791133E-03	.10582782E+00	-.82908615E-03
-.27532614E-03	.10502882E+00	-.25289803E-03	.10543032E+00	-.31435007E-03	.10517126E+00
-.32529574E-03	.10537747E+00	-.18610136E-03	.10533101E+00	-.81775961E-04	.10482909E+00
-.65720048E-04	.10530217E+00	-.80708432E-04	.10416080E+00	.15618909E-08	.10671029E+00
.93867946E-04	.10466663E+00	-.20363366E-04	.10566756E+00	.95786800E-04	.10600177E+00
.10559214E+00	-.71042442E-03	.10531413E+00	-.28977027E-03	.10526188E+00	.37792636E-03
.10541894E+00	.10322400E-02	.10535959E+00	.15696240E-03	.74539011E+01	-.54442732E+00
.12053785E+00	.22349036E-01	.29239663E+02	-.14506574E+00	.10562397E+00	.93867946E-04
.41694187E+02	-.34321591E+00	.10533934E+00	.72768643E-03	.10551531E+00	-.73326015E-03
-.14532534E-03	.10300267E+00	-.12417968E-03	.10339781E+00	-.18495033E-03	.10314683E+00
-.19581334E-03	.10335106E+00	-.59677546E-04	.10330607E+00	-.63067677E+00	.15122972E+02
.39528945E-02	.90282196E+00	-.74619669E+00	.61365197E+02	.11869673E-03	.10466663E+00
-.34321591E+00	.84283250E+02	.95046478E-04	.10364813E+00	.20786385E-03	.10397332E+00
.10628042E+00	.13178211E+00	.12073385E+00	.98022907E-01	.12804611E+00	.59038925E-01
.12139342E+00	.14525949E-01	.17004915E+01	-.12553470E+00	.10536118E+00	-.87017349E-03
.10533326E+00	-.52410245E-03	.10523215E+00	.11752286E-02	.10565325E+00	-.20363366E-04
.10533934E+00	.95046478E-04	.57249792E+02	.50909450E+00	.10716961E+00	.66556060E-01
-.65450393E-01	.64869396E+00	-.85312415E-01	.48980572E+00	-.43152279E-01	.77796484E+00
.70444469E-02	.76481876E+00	-.16672107E+00	.60715894E+01	.55656930E-03	.10379588E+00
.57252614E-03	.10426887E+00	.55551747E-03	.10315158E+00	.63791133E-03	.10566756E+00
.72768643E-03	.10364813E+00	.50909450E+00	.12416053E+03	-.49710307E-01	.55381277E+00
.97460001E-01	-.16405831E+00	.10956595E+00	-.16302126E+00	.98283278E-01	-.16409127E+00
.89982887E-01	-.16608263E+00	.10163247E+00	-.15687511E+00	.10553123E+00	-.75224545E-03
.10550397E+00	-.40851426E-03	.10540496E+00	.12927935E-02	.10582782E+00	.95786800E-04
.10551531E+00	.20786385E-03	.10716961E+00	-.49710307E-01	.10091795E+03	-.53394741E+01

SECTION VII

NCS/JMR SATELLITE SYSTEM

NCS/JMR-1 SATELLITE SYSTEM

INTRODUCTION:

The JMR-1 Doppler Survey Set is a portable receiving and data recording system which receives the Navy Navigation Satellite System (NNSS) transmissions; formats and records orbital and doppler data on digital cassette tapes for later processing in a computer. The JMR-1 Survey Set can be connected directly to the computer for 'Real-time' observation of Satellite passes with the cassette tapes serving as back-up.

The entire set can be readily moved to an extremely remote area by jeep or helicopter, back-packed to the actual site, set up and operated by one man. The set will automatically record adequate data for a precision survey in one or two days of unattended operations.

A normal lead-acid car battery is all that is required to keep the unit operating for a twenty-four hour period.

Satellite data, whether gathered in 'Real-time' or processed from the cassette tapes, is reduced and combined into a three dimensional fix representing the antenna location.

FEATURES:

1. A pass programmer which turns on only during desirable Satellite passes. This drastically reduces power consumption and power supply weight.
2. An internal rechargeable battery begins frequency standard stabilization up to thirty (30) hours before arrival on site. Good Satellite data logging can then commence immediately, thus saving an additional twenty-four (24) hours on site.
3. A hermetically sealed unit, which can be operated exposed to the elements, completely unattended.
4. A 7-segment display for observation of Satellite message, doppler count, GMT time, frequency search and other recorded data.
5. Magnetic recording via cassette.
6. Auto frequency search.
7. Analog refraction correction.
8. Digital VCO.

DATA PROCESSING

Should an extensive survey using several JMR-1 Receivers be conducted, one computer installation in a central location can service all Receivers. The Software (SP-7) currently used establishing a 3-dimensional fix was written by JMR. In this program, each successive Satellite fix is based on previous pass data stored in the computer's memory since initialization. Estimates of Latitude, Longitude and Height are improved with each Satellite fix that best fits all the doppler measurements for that particular site.

Several functions may be performed by the SP-7 program including:

1. Majority Voting of the Raw Cassette Data
2. Computing Short Doppler Fixes
3. Antenna Height Solution
4. Plotting the Fixes
5. Computing Statistical Means and Probable Errors
6. Computing Alerts
7. Cassette Manipulating Functions.

Each pass is individually evaluated for acceptance into the three-dimensional matrix. This editing process is automatic and insures that only those passes falling within the quality control constraints of the program are included in the final position fix. An attempt is made to compute every fix on tape and report the result on the printer. A STATUS MESSAGE precedes each fix print-out and can be interpreted as follows:

SM01	Good Fix
SM02	Final Doppler Residual Too High (above 10)
SM03	Did not converge in 21 iterations
SM04	Not used
SM05	Difference between Lat/Lon estimate and Lat/Lon fix was too large (greater than 1500 meters)
SM06	Less than 16 dopplers remaining
SM07	Elevation angle exceeded high or low angle cut-offs (greater than 80 degrees or less than 15 degrees)
SM08	Imbalanced doppler data
SM09	Bad data

It is worth noting that the process of gathering Satellite data can be continued indefinitely; however, the final result will tend to change less and less as the true position is approached.

<u>SPECIFICATIONS:</u>	(In brief)
POWER:	By external 12 V battery. Average consumption 5 Watts. 10.8 to 13.5 Volts D.C.
TEMP. RANGE:	-40 °C to +55 °C
DIMENSIONS:	22 CM X 38 CM X 52 CM
WEIGHT:	16 Kg.
SATELLITE PASS PROGRAMMER:	Up to fifty (50) passes selectable.
CASSETTE CAPACITY:	Up to fifty (50) passes.
OSC. STABILITY:	Less than 5×10^{-12}/100 Sec. avg.'g time
VIBRATION:	0-100HZ .25 MM Peak Displacement 100-500HZ .025MM Peak Displacement 5 G's Max. Acceleration
DUAL CHANNEL:	150 MHZ & 400 MHZ

FIELD OPERATIONS

The NCS/JMR-1 System computes three-dimensional geographical positions referenced to the WGS-72 Spheroid. The method requires the NCS Operator to monitor several Satellite passes in order to obtain a single three dimensional (latitude, longitude and height) position fix to an RMS accuracy of ten (10) meters or less.

Orbit data and doppler information from the present constellation of six satellites are reduced on a small digital computer located on site, or a central location, into a position fix.

The NCS/JMR System has provided high quality horizontal control for many applications in Hi-Arctic and jungle environments. It is particularly suited toward the establishing of Navigational Radio Base Stations, offshore rig positioning, confirming the position of already established rigs, pipe laying, boundary surveys, plus many other applications.

ACCURACY:

Several tests have been made to evaluate the accuracy of the JMR-1. Included in this report, under APPENDIX B, can be found the following paper presented at the INTERNATIONAL GEODETIC SYMPOSIUM on SATELLITE DOPPLER POSITIONING during October 1976.

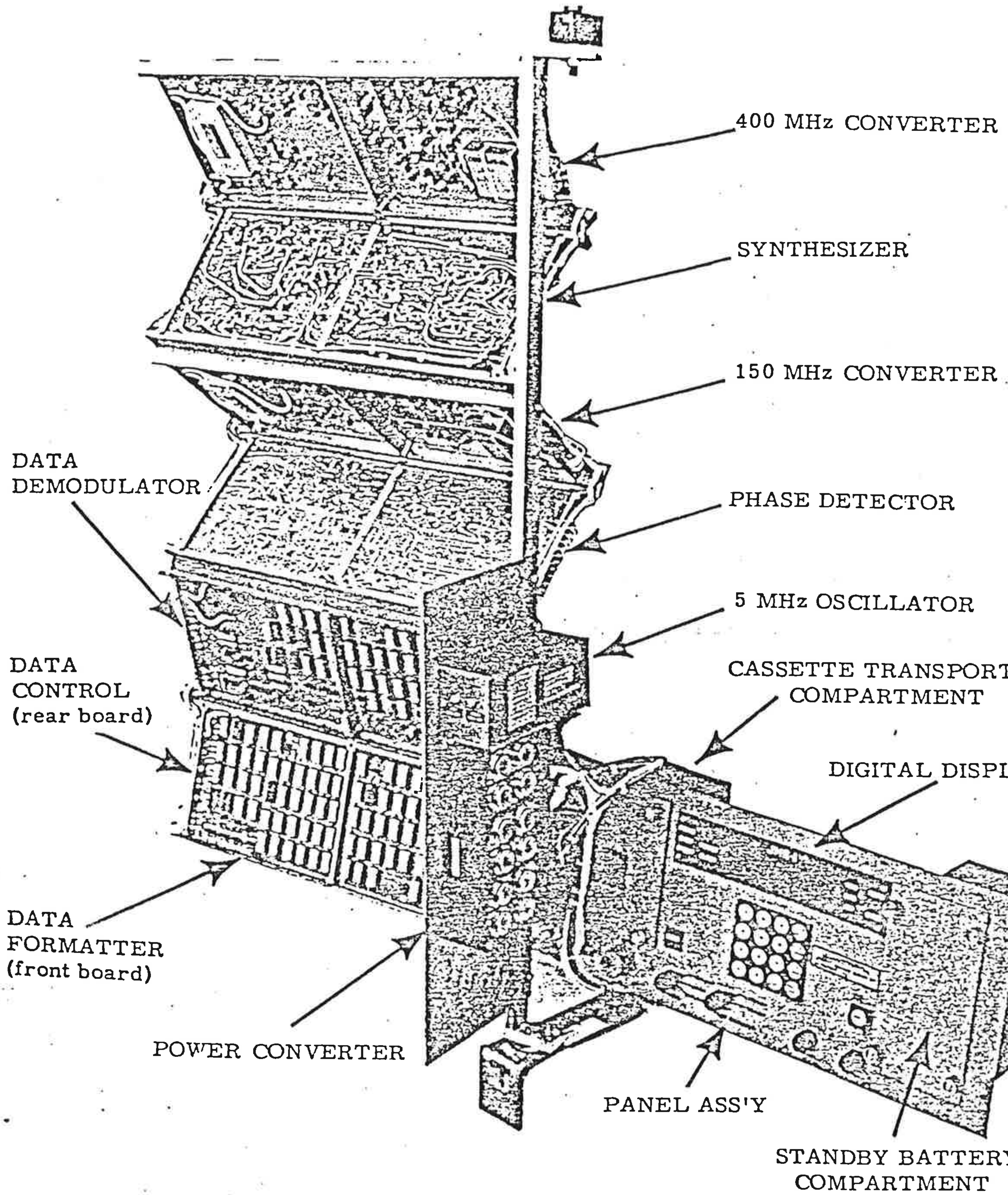


FIGURE 1.0: THE JMR-1; OPENED FOR SERVICING

SECTION VIII

NAVY NAVIGATION SATELLITE SYSTEM

1.1 INTRODUCTION

This document will provide the reader with a general understanding of the U.S. Navy Navigation Satellite System (NNSS) and of the nature of the signals which it transmits. Such a general understanding is important to full appreciation of the operation of the JMR-1 Doppler Survey Set, which records data from the NNSS transmissions from which precision three-dimensional positions can be determined.

1.2 SYSTEM SUMMARY

The JMR-1 Doppler Survey Set uses the U.S. Navy Navigation Satellites as its only references in determining the precise, three-dimensional position of a point on the Earth's surface. This satellite system has been operationally used for precise positioning, world-wide, for over 10 years. Six operational satellites are now in polar, 600 n. mile, circular orbits, some of which have been operating continuously for over six years. The satellites transmit information on a continuous basis and their signals may be received and used by anyone who has appropriate instrumentation.

The track of the satellite in its orbit must be precisely known as it is the surveyor's position reference. The data which describes the satellite position as of each two minutes into the future is predicted by the U.S. Navy and stored in the satellite's memory. The satellite is programmed to transmit this data, as modulation on its carrier frequencies, in the appropriate time slots for reception by user's equipment. The orbit data is correlated with satellite-transmitted time marks. The accuracy of this prediction data has been periodically improved over the past ten years and continuing improvement is anticipated. Orbit data of greater precision is computed by the U.S. Naval Weapons Laboratory from tracking data obtained by its tracking network during the time period of the survey.

The JMR-1 Set receives the two coherently-related satellite-transmitted signals, at frequencies of approximately 150 MHz and 400 MHz, and extracts and records timing information, predicted satellite ephemeris, and doppler shift data. The timing and ephemeral information may be taken from either signal.

1.3 THE NNSS

The NNSS is a world-wide, all weather system that enables both surveyors and navigators to determine accurate positional information from data collected during passes of the orbiting satellites.

This system consists of three major subsystems:

The ground support subsystem

The satellite subsystem

The user subsystem

1.3.1 The Ground Support Subsystem

The ground support subsystem consists of four types of stations. Tracking, Injection, Computing and Naval Observatory Stations.

A station may perform one or more of the ground support functions.

1.3.1.1 Tracking Stations

The tracking stations are located in Hawaii, California, Minnesota and Maine (see Figure 1-1). Each tracking station includes radio receiving and data processing equipment that receive and decode the satellite transmission. The tracking station antennas have a directional pattern and must be programmed to point toward the satellite throughout the duration of the pass. This antenna directivity provides greater antenna gain and offers an additional measure of discrimination against spurious signals from local transmitters. It also ensures tracking of the selected satellite during those instances when two satellites converge within radio line-of-sight. The programming data for pointing the tracking station antenna either originates at the computing center, and is routed through the central control center, or is locally derived at the tracking station. Just before the satellites time-of-rise, the antenna is pointed so as to acquire the satellite signals. As the satellite rises above the horizon, the antenna continues to follow the pass, allowing the radio receiver at the tracking station to lock on the signals. The receiver and data processing equipment decode and record the satellite message. The doppler signal is digitized and sent with satellite data to the computing center.

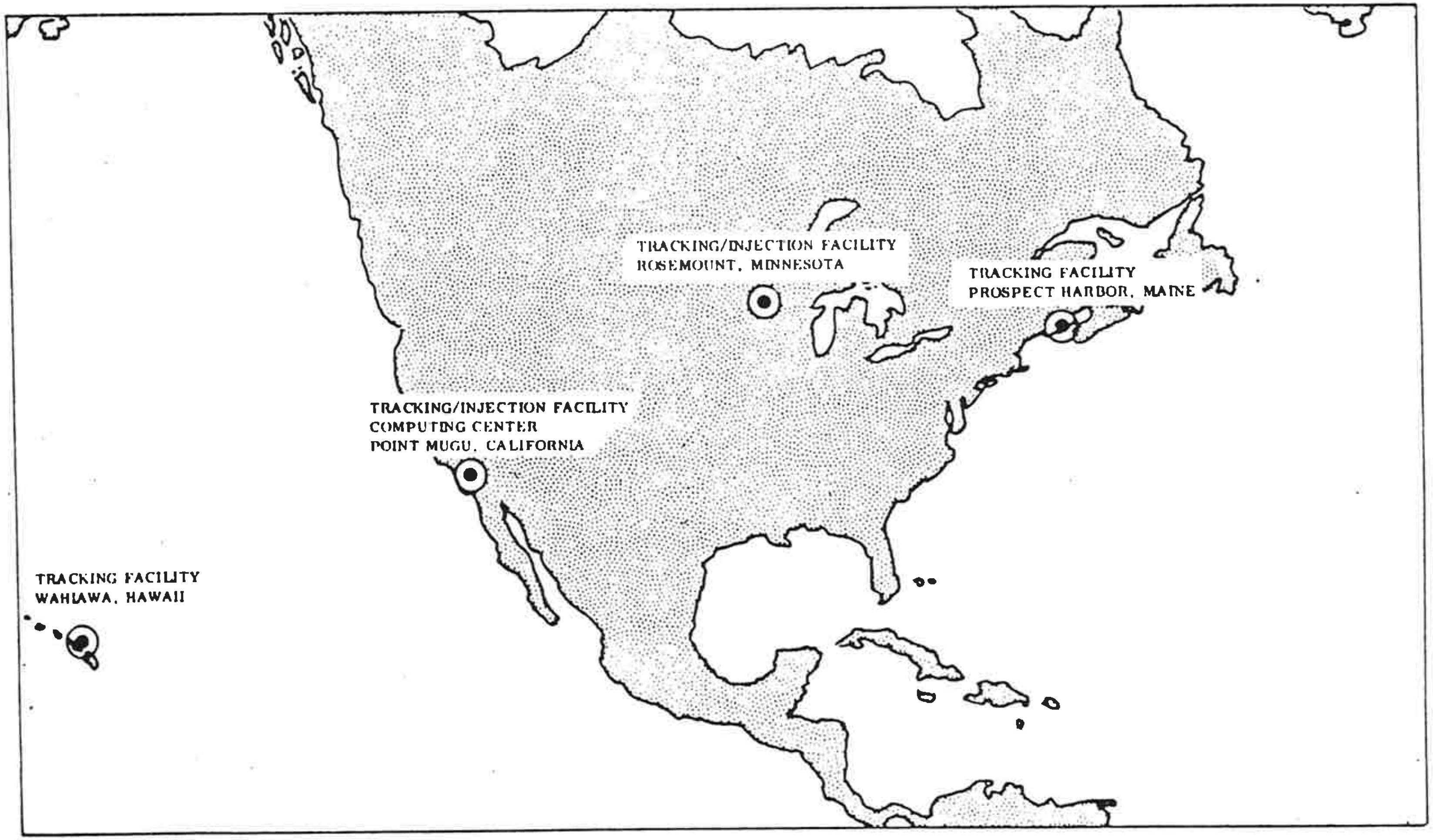


Figure 1-1. NNSS Ground Station Locations

1.3.1.2 Naval Observatory Station

The Naval Observatory receives signals during each satellite pass. During a pass, the data processing equipment compares the time of reception of the 78th bit of each two-minute message received with the even two minutes of Universal Time (UT-2). The times at which satellite time signals are received are then transmitted to the computing center.

1.3.1.3 Computing Center

The computing center continually accepts data inputs on the four satellites from the tracking stations and the Naval Observatory. Periodically, to obtain the fixed orbital parameters for a satellite, the computing center computes an orbit for each satellite that best fits the doppler curves obtained from all tracking stations. Then, using the computed orbital shape, the computing center extrapolates the position of the satellite at each even two minutes, in Universal Time, for the next 12 to 16 hours subsequent to data injection. The data, together with commands and time correction data for the satellite, and antenna-pointing orders for the injection station antenna, are supplied to the injection station.

1.3.1.4 Injection Station

The injection station, after receiving and verifying the incoming message from the computing center, stores the message until it is needed for transmission to the satellite. Just before a satellite time-of-rise, the injection station antenna is pointed to acquire, lock-on and track the satellite throughout the pass. As soon as the receiving equipment receives and locks onto the satellite signals, the injection station reads the injection data and commands from storage and transmits them to the satellite. Transmission to the satellite is on a different frequency from that used by the satellite, and the bit rate is much higher; thus, injection is completed in a matter of seconds.

The next two-minute transmission by the satellite, during the pass, contains part of the newly injected data. In the injection station, this readback is compared with the data that the satellite should be transmitting as a check for errors. Because most of the newly injected data (the variable parameters) will not be transmitted until the appropriate time during the satellite's orbit, the initial readback from the satellite includes parity check data. These data provide for error detection of the variable parameters so that the injection station can verify that the parameters were received correctly.

If no errors are detected, injection is complete. If one or more errors are noted, injection is repeated at two-minute intervals (updating the variable parameters as necessary) until the satellite transmission is verified as being correct or until the satellite is no longer available for data injection.

Once data injection is complete, the satellite continues to transmit its normal two-minute messages. Any time corrections for the satellite clock and any commands for the satellite (such as changeover to the standby oscillator, cease transmission, and the like) are also performed during the period of data injection. These precautions ensure that the navigational equipment, which depends on accurate satellite data for determining its position, is provided the best possible data from each satellite.

1.3.2 Satellite Subsystem

Each of the satellites is placed in a nominally circular polar orbit at an altitude of 400-700 (nominal 600) nautical miles. The orbital planes of the satellites intersect at the earth's rotational axis and at launch are spaced optimally apart in longitude at the equator. Thus, since the orbital planes remain essentially fixed in space, the satellites appear to traverse the longitudinal meridians as the earth rotates beneath them. The NNSS satellites provide contact anywhere on earth almost on an hourly basis. Figure 1-2 illustrates satellite availability for 4 satellites. Six satellites are currently in use.

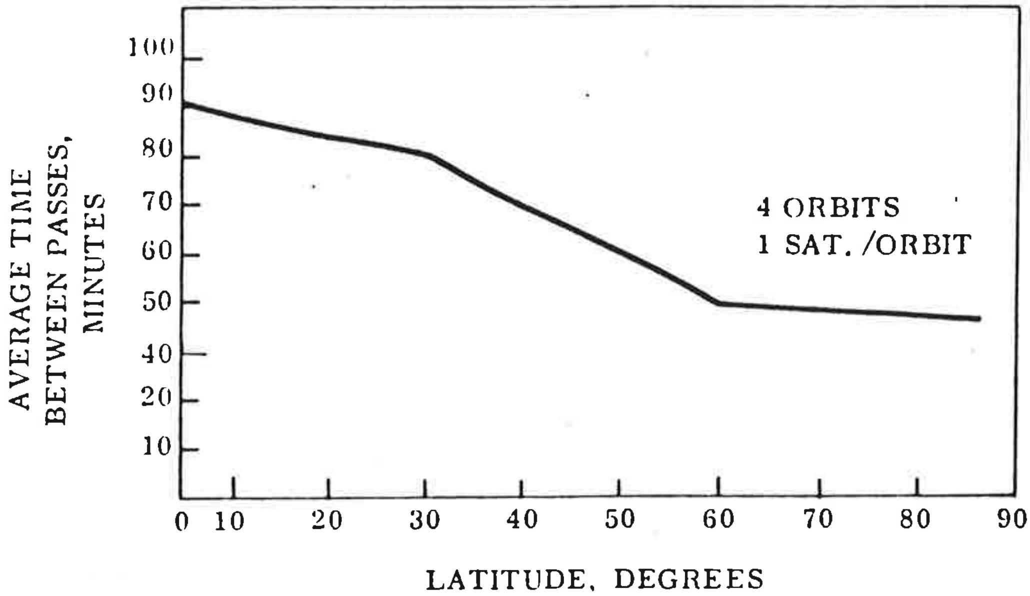


Figure 1-2. Satellite Availability Chart

Each satellite orbits the earth in approximately 108 minutes. Through its useful life, each satellite continuously transmits the following phase-modulated data as two-minute messages on two rf carriers: two-minute mark synchronization signals, a 400 Hz "beep" signal, and fixed and variable parameters describing its own orbit.

The fixed parameters describe the satellites nominal orbit and are accurate for a 12 to 16 hour interval. The variable parameters describe the fine structure in the satellite's nominal orbit as a function of time and are correct only for the time at which they are transmitted by the satellite. Thus, the satellite's memory stores sufficient variable parameters to describe its orbit at two-minute intervals between subsequent injections of data into its memory. Each transmission is timed so that the end of the 78th bit of each two minutes message (the last bit of the synchronization signal) coincides with the even two minutes of UT-2. Thus, the satellites also serve as an accurate time reference for all navigators that are equipped with an adequate system to receive and decode satellite transmissions.

All data transmitted by a satellite that does not change, such as synchronization and identification signals, etc. are wired into the satellite's memory. All data that changes with time, such as the parameters of its orbits, are replaced at 12 to 16 hour intervals by transmission from an injection station.

1.3.2.1 NNSS Satellite

Figure 1-3 illustrates a simplified diagram of the electronics contained in a NNSS satellite.

The 5 MHz oscillator provides the base frequency for the transmitted signals and the internal timing.

Each of the transmitters are in continuous operation. The 400 MHz output is offset by 32 kHz which results in an emitted frequency of 399.968 MHz. The 150 MHz output is offset by 12 kHz which results in an emitted frequency of 149.988 MHz.

The internal timing will be utilized for memory gating, both for the transmission of data and input of the injected data, and for the wired functions.

Memory consists of 636 39-bit words. Memory contains, in addition to other datum, the fixed and variable parameters of the orbits required for navigational fix.

1.3.2.2 Satellite Radiation Considerations

The satellite transmitter has an output capability of approximately 1.5 watts. With such a low power availability a radiation pattern was chosen to result in the maximum radiated power at the desired angular displacement. (Figure 1-4 illustrates the radiation pattern of the satellite.) The radiation pattern results in maximum radiated power at the angles at which the distance will be the greatest, and minimum radiation at angles at which the distance is the shortest. The Vector-distance relationship is illustrated by Figure 1-5.

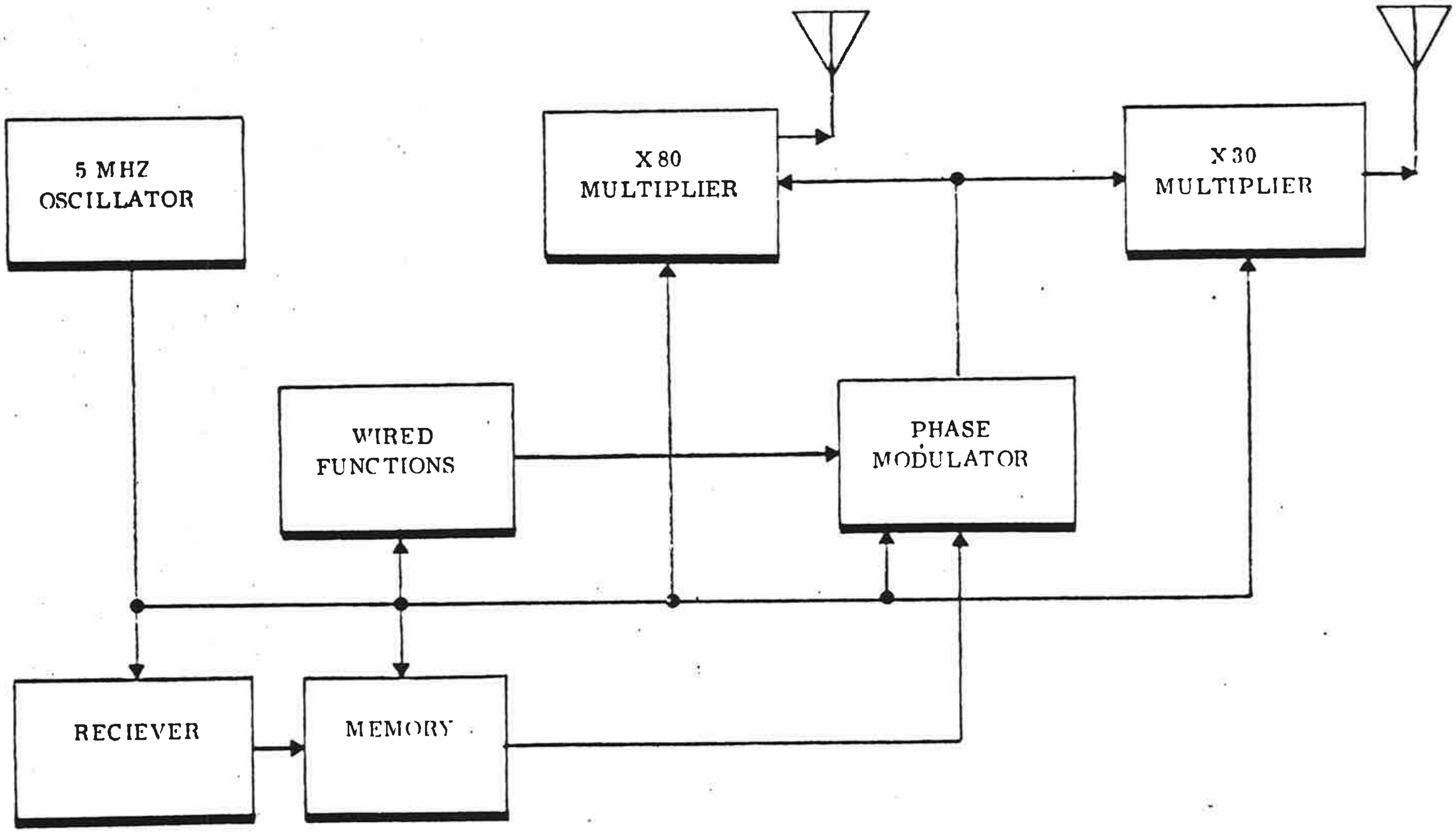


Figure 1-3. NNSS Satellite, Simplified

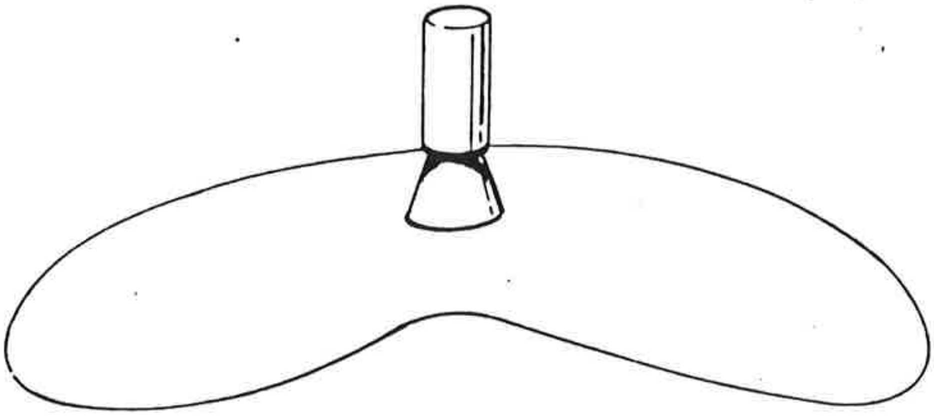


Figure 1-4. Satellite Radiation Pattern

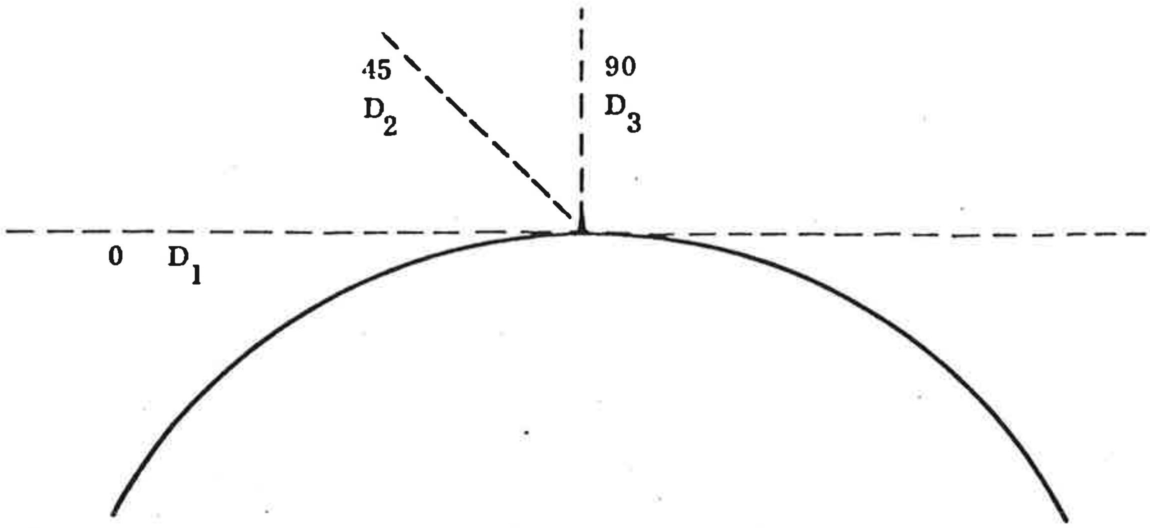


Figure 1-5. Angular Position VS. Distance

The satellite antenna is designed for left-hand circularly polarized radiation at both 150 and 400 MHz. This allows maximum signal energy transfer to a left-hand circularly polarized receiving antenna, and also optimum rejection of reflected and re-radiated signals at the circularly-polarized receiving antenna. An anomaly in the satellite's 400 MHz radiation pattern requires use of a vertically-polarized receiving antenna at that frequency until new satellites with corrected radiation patterns are launched.

Any time that the satellite is within radio line-of-sight and the angle at time of closest approach is equal to or greater than 15 degrees and equal to or less than 75 degrees, the satellites transmission may be used to compute the exact position on the earth of the positioning equipment. Satellite passes suitable for use in obtaining a position fix will generally occur at least every two hours.

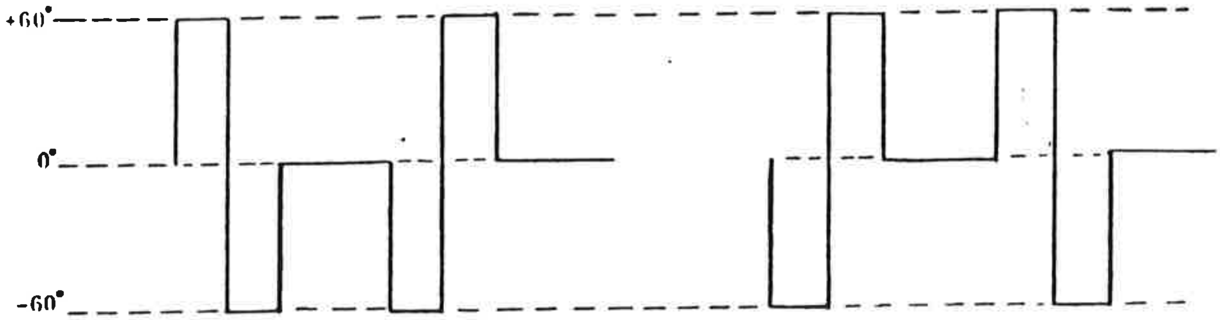
1.3.2.3 Satellite Transmission Format

The data transmitted by the satellite is in the form of phase modulation on the carrier frequency. A data bit requires approximately 20 ms.

A bit time is divided into two time periods of 10 ms called doublet times.

Each doublet time period consists of four equal time periods of 2.5 ms. The first two time periods are data periods. The last two time periods are "rest" periods. The data periods are of equal and opposite phase shift. The rest time has no associated phase shift.

The doublet pairs representing a logic quantity (1 or 0) are illustrated by Figure 1-6.



a. Binary 1 b. Binary 0

Figure 1-6. Binary Data Represented by Doublets

The data transmitted is in the form of binary-coded-decimal-excess 3. Table 1-1 compares decimal/octal/BCD/BCDXS3 coding for the decimal digits.

TABLE 1-1. DIGITAL CODE COMPARISON

DECIMAL	OCTAL	BCD	BCDXS3
0	0	0000	0011
1	1	0001	0100
2	2	0010	0101
3	3	0011	0110
4	4	0100	0111
5	5	0101	1000
6	6	0110	1001
7	7	0111	1010
8	10	1000	1011
9	11	1001	1100

Each satellite data word is 39 bits in length. This represents 9 digits, 36 bits, and three bits that are not utilized for positional information. Figure 1-7 illustrates the 9 digits of a typical satellite word.

1.3.2.4 Satellite Message

The satellite message consists of 156 words of 39 bits and a word of 19 bits, a total of 6103 bits which is transmitted in exactly two minutes.

Refer to Table 1-2 during the following discussion.

The words that are of particular interest to the navigational equipment are Word 2, Word 3, Word 8 and every sixth word thereafter through Word 152.

Each of the words shall be discussed in the order of their occurrence.

WORD 2 - the last 25 bits of this word contain a distinctive pattern that is used for synchronization. This pattern is a logic 0 bit followed by 23 bits of logic 1 followed by a logic 0 bit. The end of the last logic 0 bit coincides with the start of Word 3.

WORD 3 - The exact start of word 3 is the two minute time mark. During word 3 the phase modulation pattern is altered so that a 400 Hz tone may be heard. Time marks emitted by the satellite are accurate to about 200 us.

Although the absolute time accuracy of a time mark may be no better than 200 us, the two minute accuracy between marks is accurate to about 10 us.

WORD 8, 14, 20, 26, 32, 38, 44, 50 - these are the Ephemeral data words.

WORD 56, 62, 68, 74, 80, 86, 92, 98
104, 110, 116, 122, 128, 134,
140, 146, 150 - these are the Kepler data words.

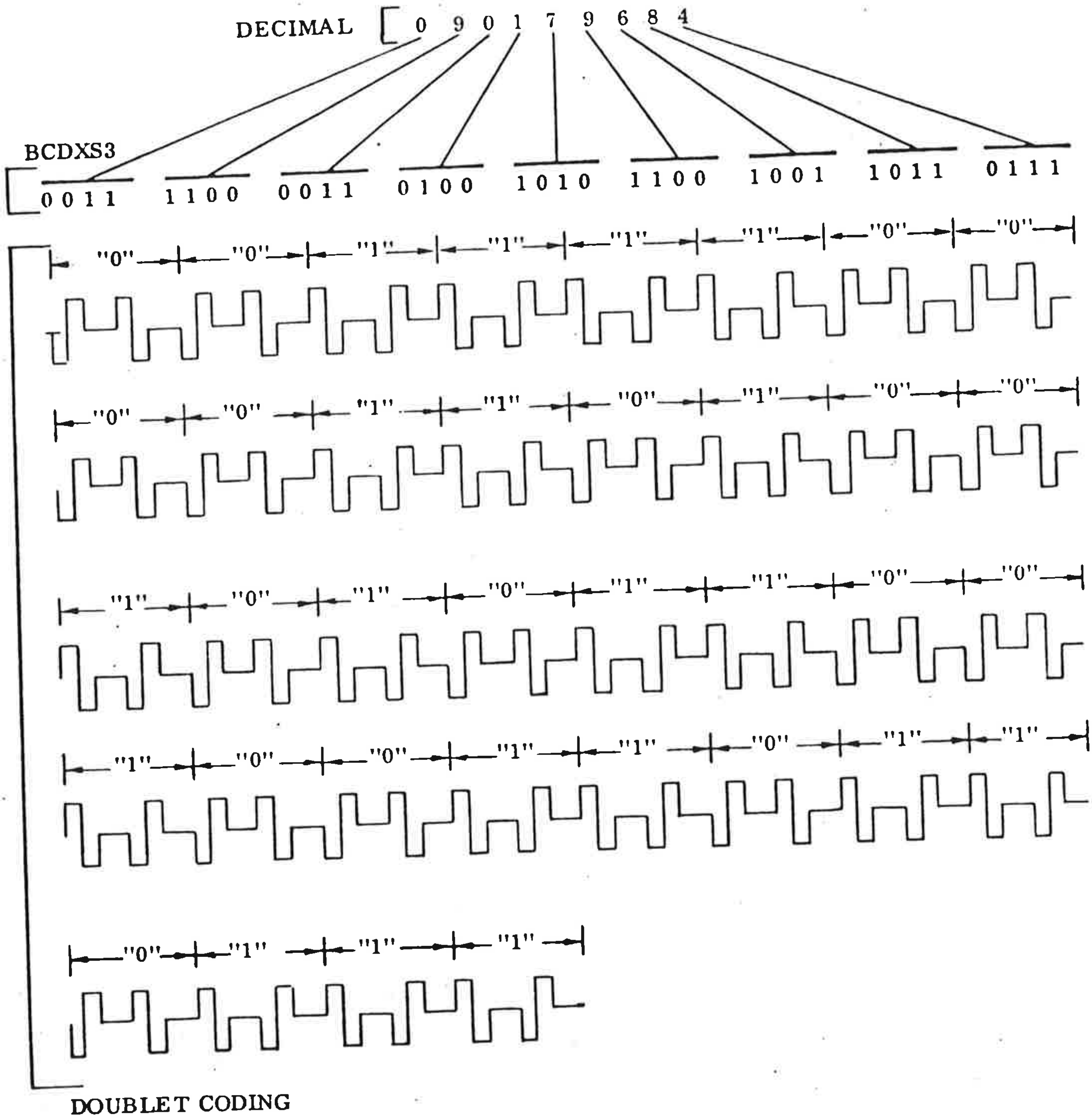


Figure 1-7. Satellite Word Code Format

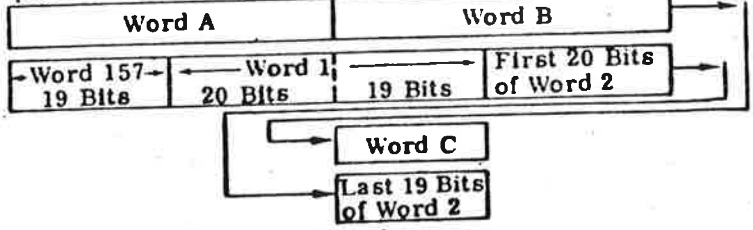
TABLE 1-2. ORGANIZATION OF SATELLITE MESSAGE

Two Minute Time Mark

LINE NUMBER							
1	3	4	5	6	7	8	1st Ephemeral Word
2	9	10	11	12	13	14	2nd Ephermeral Word
3	15	16	17	18	19	20	
4	21	22	23	24	25	26	
5	27	28	29	30	31	32	
6	33	34	35	36	37	38	
7	39	40	41	42	43	44	
8	45	46	47	48	49	50	8th Ephemeral Word
9	51	52	53	54	55	56	1st Fixed Word
10	57	58	59	60	61	62	2nd Fixed Word
11	63	64	65	66	67	68	
12	69	70	71	72	73	74	
13	75	76	77	78	79	80	
14	81	82	83	84	85	86	
15	87	88	89	90	91	92	
16	93	94	95	96	97	98	
17	99	100	101	102	103	104	
18	105	106	107	108	109	110	
19	111	112	113	114	115	116	
20	117	118	119	120	121	122	
21	123	124	125	126	127	128	
22	129	130	131	132	133	134	
23	135	136	137	138	139	140	
24	141	142	144	144	145	146	
25	147	148	149	150	151	152	17th Fixed Word
26	153	154	155	156	A	B	
27						C	

Note: Word A - Word 157 (19 bits) plus first 20 bits of word one
Word B - Last 19 bits of word one plus first 20 bits of word two
Word C - Last 19 bits of word two

Example:



Ephemeral Data

The ephemeral data will change each two minute segment. The manner in which the data changes is illustrated in Figure 1-8. Notice that the words shift and a new word is inserted in the word 50 position.

WORD POSITION	1ST TWO-MINUTE SEGMENT	2ND TWO-MINUTE SEGMENT	3RD TWO-MINUTE SEGMENT
8	080490390	090179684	500730930
14	090179684	500730930	510821264
20	500730930	510821264	620871610
26	510821264	620871610	730901950
32	620871610	730901950	540892288
38	730901950	540892288	300862570
44	540892288	300862570	010802817
50	300862570	010802817	120712990

Figure 1-8. Ephemeral Data, an Example

The quantities contained in the ephemeral data words are:

t_k - the number of two minute increments past the hour or half hour.

NOTE

The real value of t_k is <u>only</u> true if the word occupies the WORD 26 position in the message.

ΔE_k - the incremental eccentric anomaly.

(ΔE_k = ±.0XXX degrees.)

ΔA_k - the incremental length of semi-major axis of orbit ellipse.

(ΔA_k = ±X.XX kilometers.)

n_k - the incremental out-of-plane component of the satellite. Since the desired magnitude of n_k is ±.XX kilometers, two n_k digits are required. The process of obtaining n_k is explained as part of Table 1-4.

Figure 1-9 illustrates the position, in an ephemeral word, of each ephemeral quantity.

1	2	3	4	5	6	7	8	9
t_k		ΔE_k			ΔA_k			n_k

Figure 1-9. Format of an Ephemeral Word

To decode an ephemeral word the following steps must be performed.

a. To arrive at a value for t_k:

1. Select word 26 of the first two minute segment. (From Figure 1-8, 510821264)
2. Decode the first digit. (From Table 1-3, 5 = + -1)
3. The number from step 2 (1) and the second digit from the selected ephemeral word results in the value of t_k. (11)
4. Multiply t_k by 2. (11 x 2 = 22) the time is 22 minutes past the hour or half-hour.

b. To arrive at a value for ΔE_k:

1. Extract the first sign obtained in a . 2 (+).
2. Extract the third through fifth digit of the ephemeral word. (510821264 = 082)
3. Attach the sign from step b . 1. to the quantity from step B. 2. (+082) this is the signed value of ΔE_k.

c. To arrive at a value for ΔA_k:

1. Extract the second sign obtained in a . 2(-).
2. Extract the sixth through eighth digit of the ephemeral word. (510821264 = 126)
3. Attach the sign from step c. 1 to the quantity from step c. 2. (-126). This is the signed value of ΔA_k.

TABLE 1-3. DIGIT DECODE SIGN AND VALUE

DECIMAL NUMBER	DECODE	FIRST DIGIT OF t_k	SIGN OF ΔE_k	SIGN OF ΔA_k	DECODED FOR n_k
0	++0	0	+	+	-0
1	+-0	0	+	-	-4
2	-+0	0	-	+	-3
3	--0	0	-	-	-2
4	++1	1	+	+	-1
5	+-1	1	+	-	+0
6	-+1	1	-	+	+1
7	--1	1	-	-	+2
8	+				+3
9	-				+4

NOTE: 8 and 9 are reserved for sign and values of n_k and Keppler data signs.

d. To arrive at a value for n_k:

1. Extract the ninth digit of the ephemeral word. (51082126<u>4</u> = 4)
2. Decode the digit. (From Table 1-3, 4 = -1)
3. Extract the ninth digit from the next ephemeral word. (62087161<u>0</u> = 0)
4. Attach the sign and value from step d.2 to the quantity from step d.3 (-10) this is the signed value of n_k.

When decoding is completed the data in Figure 1-8 would be as shown in Figure 1-10.

Fixed Data

Table 1-4 describes the fixed data quantities. To decode the first digit for sign consult Table 1-3.

WORD POSITION	FIRST TWO MINUTES				SECOND TWO MINUTES				THIRD TWO MINUTES			
	t_k	ΔE_k	ΔA_k	n_k	t_k	ΔE_k	ΔA_k	n_k	t_k	ΔE_k	ΔA_k	n_k
8		+049	+039	-04		+017	+968	-10		+073	-93	-04
14		+017	+968	-10		+073	-093	-04		+082	-126	-10
20		+073	-093	-04		+082	-126	-10		-087	+161	-00
26	11	+082	-126	-10	12	-087	+161	-00	13	-090	-195	-08
32		-087	+161	-00		-090	-195	-08		+089	-228	+30
38		-090	-195	-08		+089	-228	+30		-086	-257	-07
44		+089	-228	+30		-086	-257	-07		+080	+281	+20
50		-086	-257	-07		+080	+281	+20		+071	-299	-00

NOTE: t_k is decoded for word 26 only.

Figure 1-10. Decoded Ephemeral Data, an Example

1.3.2.5 The Doppler Factor

The navigational solution is based upon "the apparent frequency shift of the transmitted frequency, at the receiving antenna, due to the relative motion of the transmitting station, satellite, and the receiving station" or, doppler frequency shift.

As the satellite approaches, the doppler effect is such that the frequency appears to increase, and as the satellite recedes, the doppler effect is such that the frequency appears to decrease. (See Figure 1-11.)

Every cycle of increase in doppler means that the satellite has moved one wavelength nearer. This is a precise measurement since a wavelength, at 400 MHz, is 3/4 meter.

The doppler shift measurement is made by accumulating doppler cycle counts for each two-minute satellite data interval or submultiple thereof.

TABLE 1-4. FIXED DATA QUANTITIES

SATELLITE WORD	QUANTITY	DESCRIPTION
56	t_p	Time of satellite perigee (minutes)
62	n	Mean motion of satellite (degrees/ minute) X . X X X X X X
68	ω	Argument of perigee at t_p (degrees)
74	$\dot{\omega}$	Precession rate of perigee (degrees/ minute)
80	ϵ	Eccentricity
86	A_o	Mean semi-major axis (kilometers)
92	Ω	Right ascension of ascending mode at t_p (degrees)
98	$\dot{\Omega}$	Precession rate of mode (degrees/ minute)
104	C_i	Cosine of inclination
110	$\wedge_G$	Longitude of Greenwich at t_p (degrees)
116	—	Satellite Identification Number
122	t_i	Time of last injection (fiducial inverval & day No.)
128	S_i	Sine of inclination
134	Frequency	Offset of satellite oscillator in parts per million below 150 & 400 MHz
140	—	BCDXS3 zeros except during injection
146	—	BCDXS3 zeros except during injection
152	—	BCDXS3 zeros except during injection

Word 128 is distinctive and may be used to identify the satellite. At the time this book was written the following "signatures" were applicable.

SATELLITE IDENTIFICATION NUMBER	SIGNATURE SINE OF INCLINATION
30120	809999930
30130	809999800
30140	809999160
30180	810000000
30190	809999990
30200	809999960

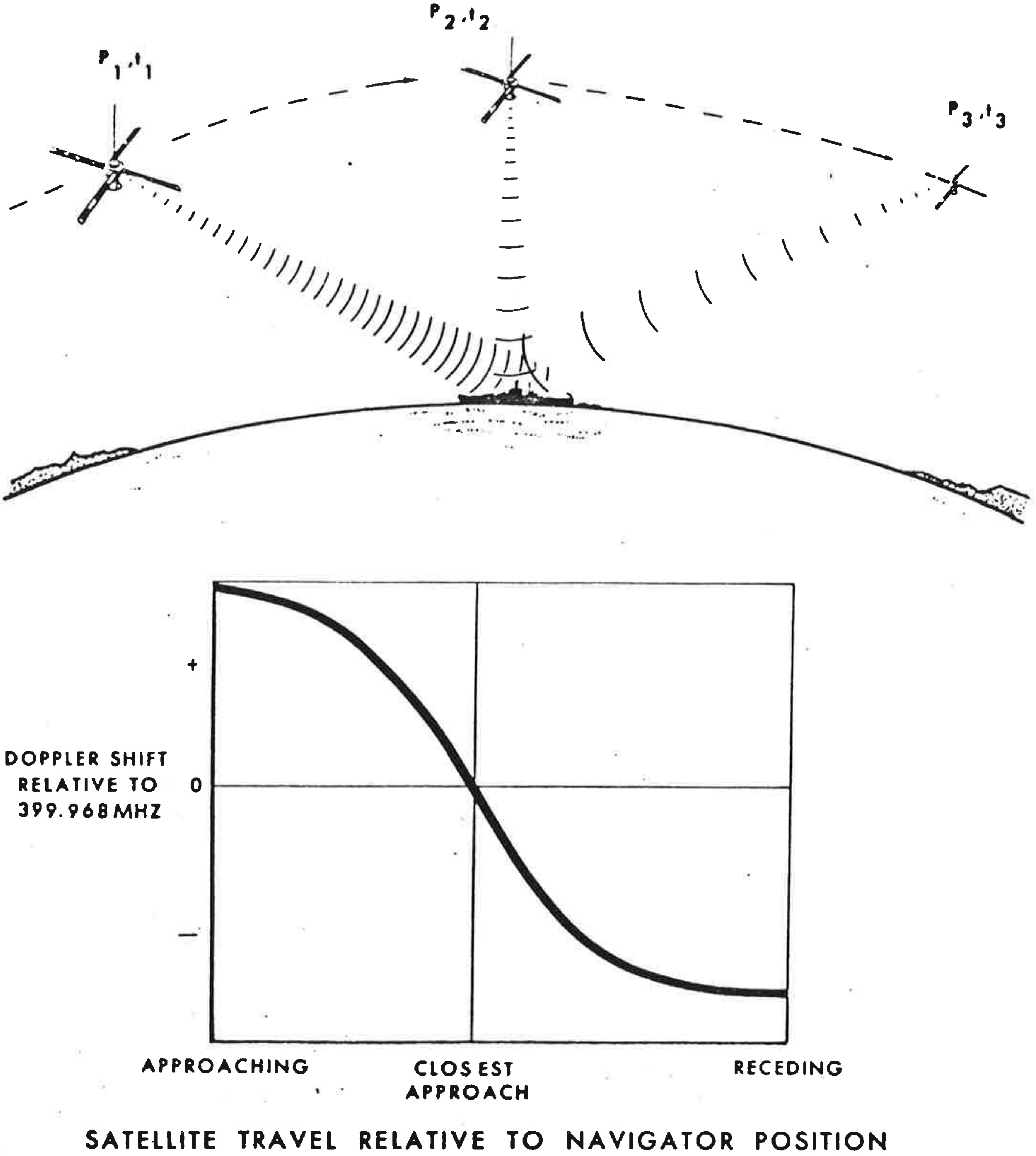


Figure 1-11. Satellite 400 MHz-Signal Subjected to Doppler Effect

1.3.2.6 Signal Refraction

The satellite could transmit the data using a single ultra-high frequency. This frequency would travel along a line-of-sight path towards the receiving antenna. However, while passing through the ionosphere the propagation path becomes bent, or refracted. (See Figure 1-12.) Refraction of the signal path affects the accuracy of the receiver doppler count, producing errors in the computed navigation fix. To correct the major part of this effect a second transmission frequency is employed. During propagation both frequencies are affected by refraction but, by different amounts. The refraction difference is measured by the receiver and used to correct the doppler count. If this correction is not made, the position fix may be in error by hundreds of feet, particularly during the daytime. Thus refraction correction is necessary for full accuracy.

1.3.3 The User Subsystem Equipment

The user's system is the final link in the NNSS System. This equipment receives the signals transmitted by the satellite, measures the doppler shift, decodes the satellite message, and organizes the data for position fix computation by a computer.

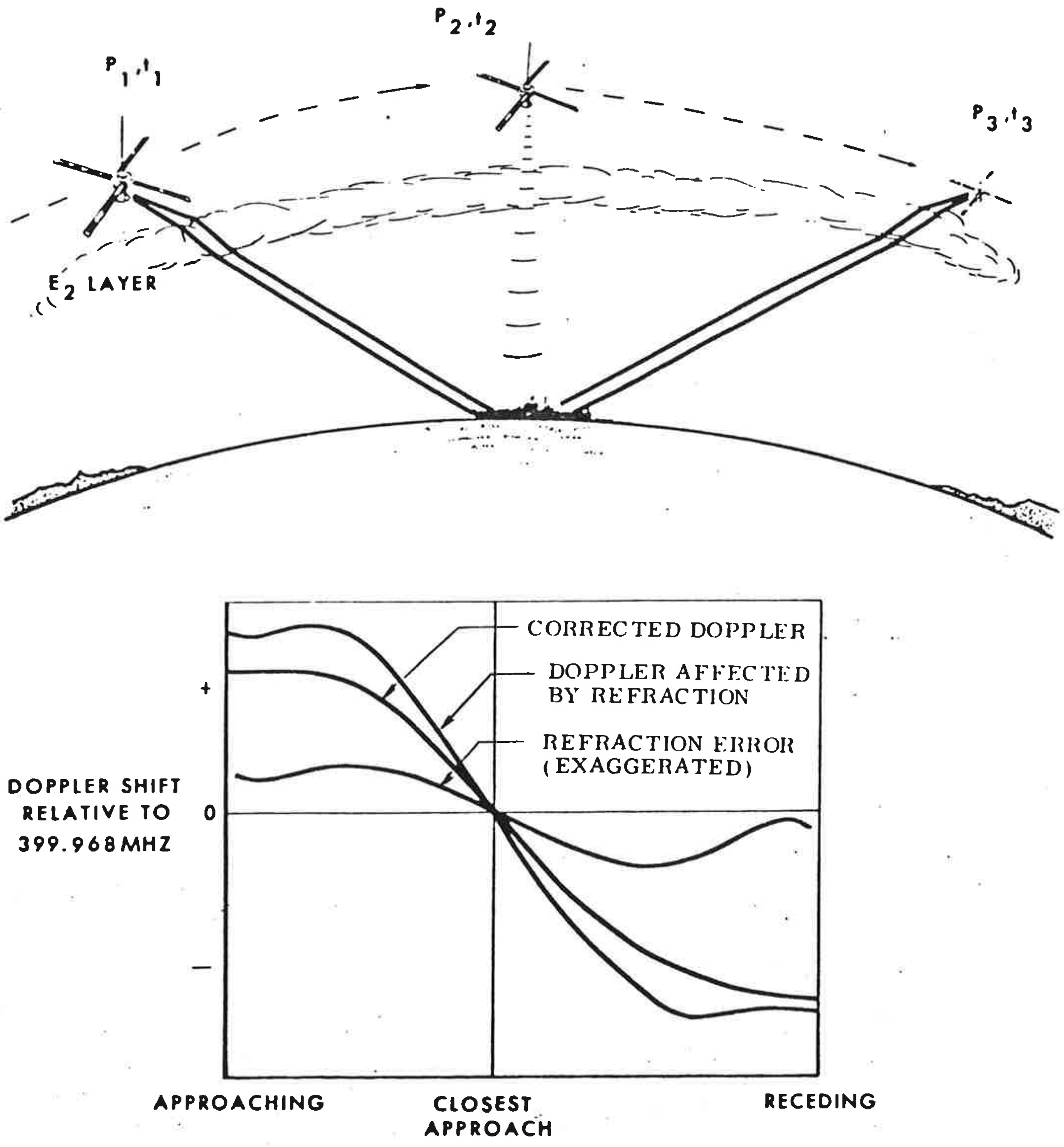


Figure 1-12. Satellite 400 MHz Signal Subjected to Refraction

The user's system consists of the following basic elements:

- A dual frequency antenna
- A dual frequency phase-lock receiver
- A precision 5 MHz frequency standard
- A digital processing unit

1.3.3.1 The Navigational Fix

As stated, the satellite describes the orbital position of the satellite every two minutes, on the even two minutes. To obtain a position fix, it is necessary only to determine the user's location relative to the known location of the satellite. The user's system employs an "integrated" doppler measurement for this purpose. In Figure 1-13, positions for the satellite in its orbit are shown for times t_1 through t_4. The slant range from ship to satellite is given for S_1 through S_4. From Figure 1-12, it is evident that the number of wavelengths, of the transmitted signal, enroute at time t_1 along S_1 is greater that at time t_2 along S_2. Every doppler cycle received means that the satellite has moved one wavelength closer. The satellite's transmission frequencies are 400 MHz offset by 32 KHz (399.968 MHz) and 150 MHz offset by 12 KHz (19.988 MHz). This offset allows the user system to obtain unambiguous doppler information during a satellite pass when using a reference oscillator whose frequency is an exact sub-multiple of 400 MHz. The integrated doppler measurement is simply the count of the number of doppler cycles received between t_1 and t_2, which is a direct measure of the total changes of slant range during that time interval. Since the satellite positions, at t_1 and t_2, are known, the receiver must be on some surface defined by the measured slant range difference between these points. This surface is a hyperboloid of revolution with the foci at the known satellite position. The receiver must be located somewhere along the curve defined by the intersection of this hyperboloid and the earth's surface.

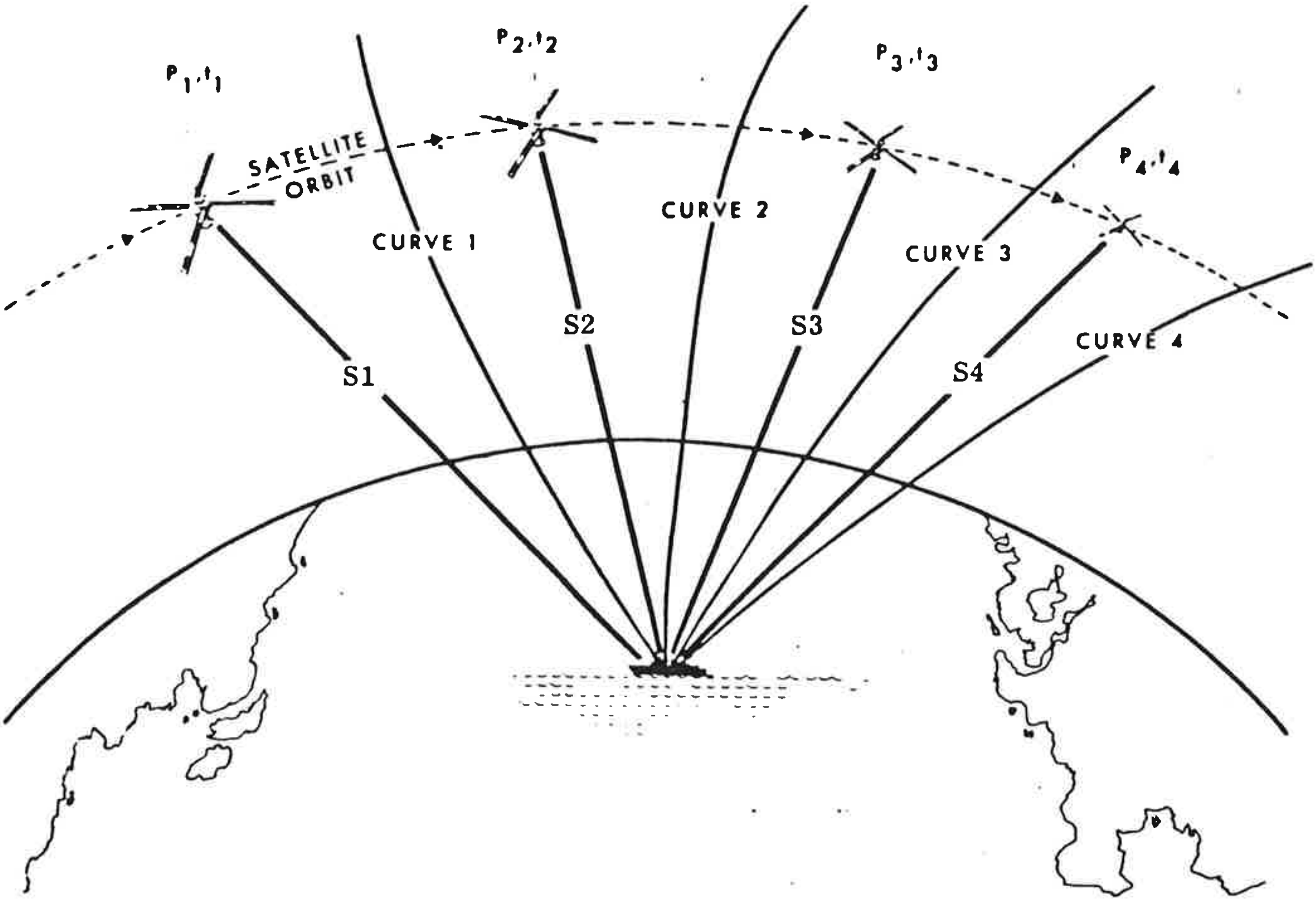


Figure 1-13. Obtaining a Position Fix Using Satellite Navigation Equipment

The next doppler count will define a second curve, and the intersection of this plus an additional curve (shown in Figure 1-13) results in a navigational fix. At least three doppler counts are required in order to obtain a position fix. As many as nine two-minute counts may be recorded per satellite pass, and all are used to improve the accuracy of the computed position fix.

1.3.3.2 System Operation

Regardless of the configuration involved, the system operation is basically the same. The receiving equipment of the user's system receives the incoming satellite message, extracts the message information, measures the doppler shift and records the information for entry into a computer for fix computation.

The user system will extract and measure the following from the received signals.

- Measured doppler
- Measured refraction
- Satellite orbital data
- Timing information.

The received signals will be shifted by doppler and/or refraction. The doppler effect is directly proportional to the transmitted frequency. Therefore, the doppler effect is greatest on the 400 MHz signal and will be measured from the 400 MHz signal. Refraction effects are inversely proportional to the transmitted frequency. Therefore, the refraction measurement will be accomplished on the 150 MHz signal.

Before meaningful data can be extracted from the received satellite message, the user system must be synchronized with its modulation. Synchronization is accomplished in three steps.

Step 1. DOUBLET SYNCHRONIZATION

The receiver allots 16 seconds for the internal doublet clock (≈100 Hz) to be synchronized with the received doublets.

Step 2 BIT SYNCHRONIZATION

The receiver requires one or two seconds after doublet synchronization for the internal bit clock (≈50 Hz) to be synchronized with the received bits.

Step 3 MESSAGE SYNCHRONIZATION

After doublet and bit synchronization have been accomplished, the receiver will search for the distinctive pattern that appears in satellite word 2 and, at the time that the full pattern is recognized (the start of satellite word 3) message synchronization is accomplished.