GEOSERVICES
MARITIME PVT. LTD.

REPORT ON TOPOGRAPHIC & BATHYMETRIC SURVEY FOR ASSESSMENT OF RESERVOIR CAPACITY & SEDIMENTATION IN HARNAV RESERVOIR, GUJARAT, INDIA UNDER NATIONAL HYDROLOGY PROJECT

GMPL REPORT NUMBER: P - SUR-BATHY-009-2020-21-WRD- HARNAV
SURVEY PERIOD: Bathymetry: 26 FEB TO 28 FEB 2021.
Topography: 25 MAR TO 26 MAR 2021

Prepared for:	**Water Resources Investigation Division, Ahmedabad** **(Govt. Of Gujarat)**
Client Reference:	**Executive Engineer** **Water resources investigation Division Ahmedabad.**

Equity
Efficiency
Sustainability
WRD

LOCATION MAP

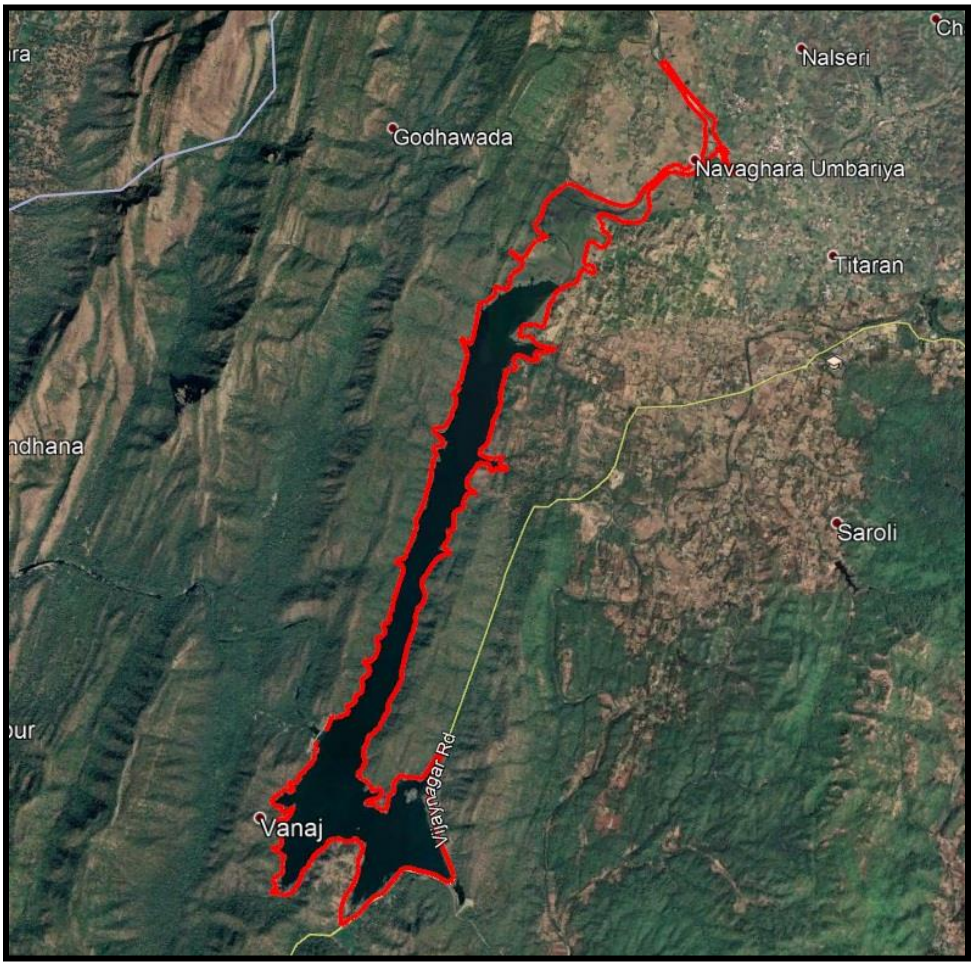

Figure 1.1-1 LOCATION MAP

LOCATION MAP SHOWING SURVEY AREA “HARNAV DAM”, GUJARAT, INDIA

DOCUMENT ARRANGEMENT

REPORT OF SURVEY WITH CHART / DRAWING

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1 INTRODUCTION, OBJECTIVE & SCOPE OF WORK

1.1 General

Water Resources Investigation Division (WRD) has awarded the contract to Geoservices Maritime Pvt Ltd (GMPL), Navi Mumbai for carrying out Topographic and Bathymetric Survey at Harnav dam, Gujarat. The survey services provided by GMPL comprise of the provision of well-qualified survey personnel and equipment in order to obtain, interpret and report on acquired topographic & bathymetric survey data at the client specified locations.

This report contains the results of survey as against the scope of work and the methodology adopted to achieve the specifications and schedule of the survey work undertaken at Harnav dam.

1.1.1 LIST OF ABBREVIATIONS USED

CM	Central Meridian
DGPS	Differential Global Positioning System
CSRS	Canadian Spatial Reference System
FRL	Full Reservoir Level
GMPL	Geoservices Maritime Private Limited
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
KHz	Kilohertz
HSE	Health Safety Environment
MSL	Mean Sea Level
m	metre
M Cu. m	Million Cubic metre
Sq. Km	Square Kilometre
MDDL	Minimum Draw Down Level
m/s	meter per second
ms	milliseconds
MWL	Maximum Water Level
QA/QC	Quality Assurance / Quality Control
Rev	Revision
RTK	Real Time Kinematic
SBES	Single Beam Echo Sounder
TBM	Temporary Bench Mark
UTM	Universal Transverse Mercator
WGS 84	World Geodetic System 1984
WRD	Water Resources Investigation Division

1.1.2 Units

- UTM grid coordinates and all linear measurements expressed in metres (m).
- Angular values expressed in degrees (°).
- Time and dates expressed as "09:00 on 24 Jan 2021".

1.2 Objective

The client's objectives were:

i) To estimate and study the sedimentation behaviour of reservoir in different zones including horizontal zones throughout the reservoir as well as vertical zones namely dead storage, live storage and flood storage if any.

ii) To upgrade Elevation-Area-Capacity table and curves of the reservoir at regular intervals.

iii) To emphasize on the importance of conducting hydrographic surveys at regular intervals for better operation and water management of the reservoir.

1.3 Scope of Work

The Scope of work for Geoservices Maritime Pvt Ltd was to mobilise, install, interface, operate all survey systems and provide all required survey personnel to undertake Topographic and Bathymetric survey services at Harnav dam.

The detailed scope of work was:

i) To measure the water depth of the Harnav dam at with respect to MSL.

ii) Line spacing shall be 25 m with continues echo sounding.

iii) Reservoir for water level changes during survey shall be tabulated.

iv) Data processing using HYPACK software shall be used.

v) Topographic survey shall be conducted from FRL water level with reasonable overlap with hydrographic survey.

vi) The area not covered under Hydrographic survey up to Maximum Water Level (MWL) shall be surveyed by taking levels at 25 m interval (25 m x 25 m grid).

vii) To carry out the data processing and interpretation of data and preparing of results, charts and drawings.

viii) Estimation of Sedimentation in the Reservoir shall be calculated if previous data is available.

ix) Gross and Live storage capacity of the Reservoir at every 10 m interval shall be provided.

x) Cross Sections showing the bed profile at 100 m interval shall be prepared.

xi) L-Section of the Reservoir may be prepared with lowest bed level at every survey line.

2 SALIENT FEATURES OF HARNAV RESERVOIR

HARNAV RESERVOIR PROJECT		
I	**Location**	
	Coordinates	Latitude23°59'05"N Longitude73°17'55"E
	River	Harnav River
	Village	Vanaj
	Taluka	Vijaynagar
	District	Sabarkantha
II	**Reservoir Details**	
	Catchment Area	116 sq. km
	Top of Dam	336.85 m
	HFL/MWL	333.35 m
	FRL	332 m
	MDDL	
	River Bed Level	307.82 m
	Sill Level of Canal H.R	
	Dead Storage Capacity	1.70 McM
	Live Storage Capacity	19.97 McM
	Gross Storage Capacity	21.67 McM
	Area under submergence at FRL	3.1 Sq. Km
III	**Spillway Details**	
	Length	43 m
	Crest level of Spillway	323.77 m
	Type of Spillway	Ogee
	Maximum Discharge Capacity	1632 m^3/s
	Type, Nos. and Size of gate	Radial, 3, (12.5 m x 8.23 m)
	Design Flood	2140 Cumecs
IV	**H.R. Outlet Details**	
	Location	B.P.O.
	Design Discharge	100 Cusecs
	No. of H.R. Gates	2
	Size of Gates	1.067 m x 1.067 m
V	**Dam Details**	
	Type of Dam	Composite Rolled, Field type
	Length of Earthen Dam	284.50 m
	Length of N.O.F.	78.50 m
VI	**Canal Details**	
	Length of canal	20 km
	Capacity	0.56 m3/s
	Gross command area	6058 ha
	Culturable command area	4040 ha

Table 2-1 SALIENT FEATURES OF RESERVOIR

3 EXECUTIVE SUMMARY OF RESULTS

GMPL had mobilised their survey team, equipment and Survey Boat "Aqua Marina" which was deployed in the Harnav dam survey area from 26 Feb to 28 Feb 2021 to acquire bathymetric survey data and Topographic data as per mutually agreed scope and relevant survey specifications.

Pentax DGPS system, Sonarmite BTX Echo sounder (210 kHz) were utilised to acquire the bathymetric data within the Harnav dam area. A value of 1510 m/s was used as the average velocity of sound in water, which was applied in the setup during acquisition. The data so obtained was then processed and contouring was done using Hypack software. Pentax RTK / Auto level and Tripod were used for topographic survey in the area.

Topographic and bathymetric data was reduced to Mean Sea Level (MSL). All the data is plotted on scale of 1:5000 for Harnav dam area.

Three Temporary Bench Marks were established, one (TBM1) near dam top, rest two near dam ends on buildings easily accessible via Lat/long given below

The values depicted in the charts are the elevation with respect to MSL.

- The Minimum elevation within Harnav DAM is 309.54 m above MSL and
- The Maximum depth within Harnav DAM is 11.58 m
- Area Covered by bathymetric survey is 1.559 km^2
- Area Covered by topographic survey is 1.796 km^2

According to recent survey, total area of reservoir at FRL 332 m is 2.732 Sq. Km, corresponding storage capacity is 20.656 M Cu. m, and Dead storage at 317.50 m is 1.353 M Cu. m.

The comparison between 1990 and 2021(31 years) data results in a rate of siltation (silt index) of 2.82 Ham/100 Sq. Km/year. Annual percentage loss of gross storage capacity, live storage capacity and dead storage capacity is 0.15%, 0.11% and 0.66% respectively.

4 RESOURCES FOR SURVEY WORK

4.1 Personnel

Following staff were involved during the survey work.

Offshore Survey Personnel	
Name	**Function**
Amit Singh	Party Chief
Abhijith Cherapi	Surveyor
Ashish Patil	Survey Engineer
Nikhil Chavan	Land Surveyor
Onshore Project Management and Data QC	
Sudhir Walia	Project Manager
KSN Murthy	Survey Manager
Dhaval Patel	Data Processor

Table 4.1-1 LIST OF PERSONNEL

4.2 Details of Equipment used

Following equipment and survey sensors were mobilised for the Topographic and Bathymetric survey data acquisition carried out at Harnav Dam. The equipment setup and configuration diagram has been presented in Figure 4.1.

Survey Equipment/Systems Used for the Data Acquisition	
Equipment/System	**Description/Make/Model**
Software / Navigation	HYPACK Navigation and Data Acquisition Software
Positioning	Trimble DGPS
Single Beam Echo Sounder	Sonarmite BTX Echo sounder with Accessories
RTK	Pentax RTK system
Auto Level	Geomax Auto Level & Tripod
Survey Boat	“Aqua Marine” with OBM
Laptop	Dell Laptops
Power Supply	12v Battery & Inverter

Table 4.2-1 LIST OF EQUIPMENT USED FOR SURVEY

4.3 Survey Vessel

Survey Boat 'Aqua Marine' was utilised for carrying out the bathymetric survey.

4.3.1 Survey Boat Specifications

Survey Boat 'Aqua Marine' Specifications	
Length overall	3.56m
Breadth moulded	1.88m
Draft	0.50m

Table 4.3-1 SURVEY BOAT SPECIFICATIONS - 'AQUA MARINE'

4.3.2 Survey Boat Offset Diagram

The location of the various survey sensors on the survey boat 'Aqua Marine' is given in the vessel-offset diagram on the chart accompanying this report.

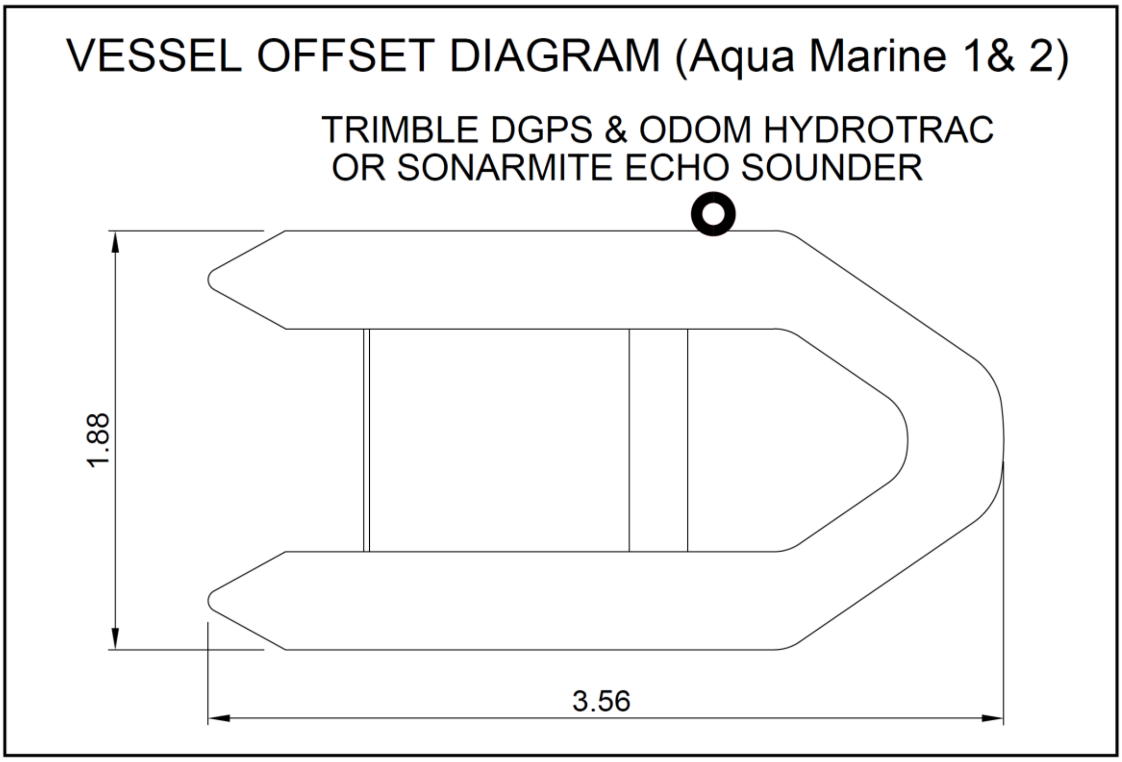


Figure 4.3-1 SURVEY BOAT ' AQUA MARINE' OFFSET DIAGRAM

5 DETAILED METHODOLOGY OF SURVEY

5.1 Mobilisation

The bathymetric survey equipment were mobilised on board “Aqua Marine” on 26 Feb 2021. After successful installation, testing and calibrations of survey equipment, the team proceeded for Data acquisition.

Pentax RTK, Geomax auto level, Tripod and necessary supporting equipment/tools were mobilised for Topographic survey.

All survey equipment was installed and configured for bathymetric Survey on board “Aqua Marine” as per Figure given below.

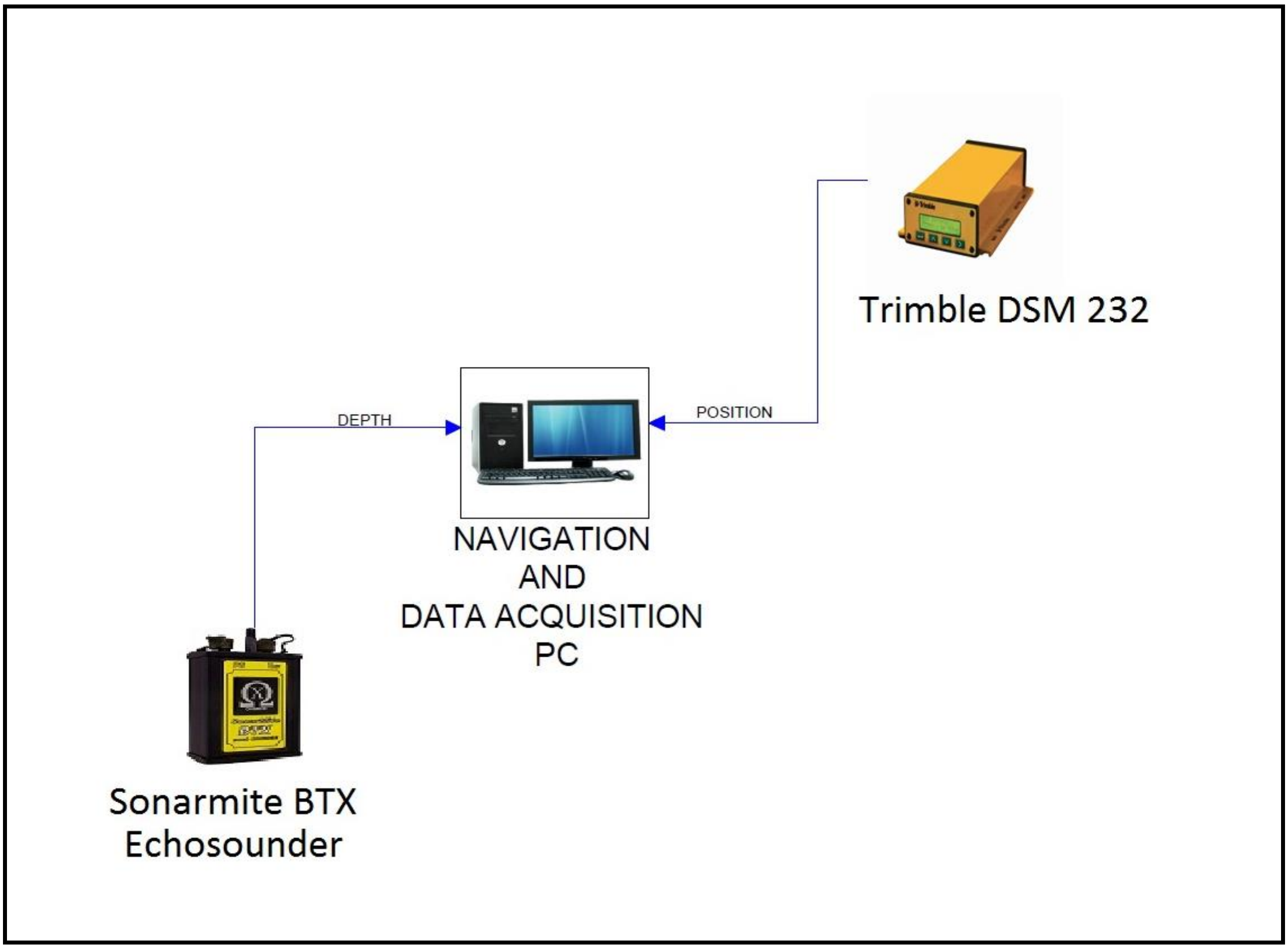


Figure 5.1-1 SBES SURVEY EQUIPMENT CONFIGURATION DIAGRAM ON BOARD

5.2 Geodesy

The survey operations were conducted in WGS 84 spheroid, Universal Transverse Mercator projection system based on following Geodetic parameters:-

Global Positioning System Geodetic Parameters	
Datum:	World Geodetic System 1984 (WGS84)
Spheroid:	World Geodetic System 1984
Semi major axis:	a = 6 378 137.000 m
Semi minor axis:	b = 6 356 752.314 245 m
Inverse Flattening:	$^1/_f$ = 298.257 223 563
Local Datum Geodetic Parameters	
Datum:	World Geodetic System 1984 (WGS84)
Spheroid:	World Geodetic System 1984
Semi major axis:	a = 6 378 137.000 m
Inverse Flattening:	$^1/_f$ = 298.257 223 563
Local Projection and Grid Parameters	
Map Projection:	Universal Transverse Mercator
Grid System:	UTM Zone 43 N
Central Meridian:	075° 00’ 00” East
Latitude of Origin:	0° 00’ 00” North
False Easting:	500 000 m
False Northing:	0 m

Table 5.2-1 GEODETIC PARAMETERS

5.3 Survey work at Field

5.3.1 Benchmark and Base station setup

The DGPS observation were made for about 4.5 Hours at Dam top near spill way. Three Temporary Bench Marks were established, one (TBM1) near dam top, rest two near dam ends on buildings easily accessible via Lat/long given below

The details of Bench Marks are presented in the table below:

BM Observation and T.BM. Information _ HARNAV DAM South Gujarat					
Location	**Latitude (N)**	**Longitude (E)**	**Easting (m)**	**Northing (m)**	**Elevation (m) W.r.t MSL**
OBS HARN	23°59'4.9984"	73°17' 56.18"	326945.689	2653579.215	336.85
TBM 1	23°59'4.5024"	73°17'55.694"	326931.81	2653564.442	336.877
TBM 2	23° 59'7.2672"	73 °17' 58.456"	327010.885	2653648.472	336.841
TBM 3	24°0' 52.6356"	73°19'15.402"	329224.354	2656863.893	353.802

Table 5.3-1 BENCH MARK DETAILS

5.3.2 Topographic and Bathymetric Survey

For topographic survey, Pentax RTK base was used for DGPS observation on top of dam, near spillway. Four Hrs. of DGPS observation was carried out on OBS HARN. RTK DGPS Base station was set up at OBS HARN, made by GMPL and configured to transmit the correction. Two rovers receiving RTK corrections from the base took spot level from water level to HFL.

For bathymetric survey, Aqua Marine boat was mobilised as shown in Survey Boat Offset Diagram. Plan line for survey was prepared parallel to dam axis and at 25 m intervals. Survey boat was run on afore mentioned plan line to acquire position as well as depth.

5.4 Survey Systems

5.4.1 Trimble DGPS:

Trimble DGPS system was used during survey.

• Differential correction signals received on board during survey operations continuously from the Satellite based augmentation system.

• The positioning data as well as heading data received with high reliability and integrity.

Trimble DGPS was the primary positioning system currently used for all the surveys. GMPL has provided, install, operate and maintain a Differential Global Positioning System (DGPS) acceptable to the EIC, which fully covered the site of the works and was constantly in operation during the all the surveys. The age of pseudo- range correctors used in position computation was not exceeded 20 seconds; however, any horizontal positioning interpolation was never exceeded the accuracy. Horizontal Dilution of Precision (HDOP) was monitored, and was never exceeded 2 nominally. Satellite geometry alone is not a sufficient statistic for determining horizontal positioning accuracy. Other variables, including satellite pseudo range residual, were used in conjunction with HDOP to estimate horizontal accuracy. A minimum of four satellites were used to compute all positions, Horizontal and Vertical offsets between the GPS antenna and transducer(s) were observed and applied with a precision better than 0.01m. The system was consisting of master receiving reference station (Base) and DGPS Navigator unit (Rover). The navigator's units (Rover) were installed on Survey launch. The composition was consisting navigational software, track plotters, data storage facilities, echo sounders, sufficient spares to enable uninterrupted operation of the system to the accuracy specified and on-board computers.

5.4.2 Single beam Echo sounder

The single beam echo sounder 'Sonarmite BTX' with an accuracy of 0.01m was deployed and in principle, higher frequency of 210 kHz was operated. Echo Sounder equipment was calibrated daily before and after use, by means of a bar-check in the survey area. The calibration results were found satisfactory.

5.4.3 HYPACK Software

HYPACK is a Windows™-based software package used primarily for hydrographic surveying and data processing.

HYPACK performs all of the tasks necessary to complete Single Beam Echo sounder data acquisition /processing from beginning to end. This all-in- one module provides the surveyor with all of the tools needed to design their survey, collect data, process it, reduce it to w.r.t MSL, and generate final products. Whether collecting hydrographic survey data or environmental data, or positioning a vessel in an engineering project, HYPACK provides the tools needed to complete the job.

This software can be interfaced simultaneously to Echo sounders and attitude sensors.

5.4.4 RTK System

Pentax RTK system consists of one Base and Rover Module was used for Topographic Survey.

- RTK DGPS Base station was set up at the BM Made by GMPL and configured to transmit the corrections.
- Pentax RTK Rover was used for DGPS Observation on the top of Dam, near spill way. 4Hrs of DGPS observation was carried out. Bench Mark elevation value of 336.85m was provided by the dam authority.

5.5 Data Acquisition and Quality Control

5.5.1 Online Data Quality Control

The online navigation computer was interfaced to Sonarmite BTX Echo Sounder system. Laptop connected to the Navigation network were time synchronized with the GPS (high precision) time signal allowing all data to be precisely time stamped.

Navigation

The DGPS system performed well at all times and the performance of the system was continuously monitored.

Echo Sounder

The digital output from the Sonarmite BTX Echo Sounder was satisfactory throughout the duration of the survey. The quality of obtained soundings were verified by running suitable cross lines and depths were found to be matching.

5.5.2 Data Processing

The bathymetric survey data was logged using Hypack on Navigation System. The quality of the bathymetric data acquired in the field was monitored continuously onboard the survey boat. Survey data was processed in office and handed over to the client.

5.6 Quality Assurance and HSE Procedures

GMPL has fully documented and self-audited Quality Assurance and Health, Safety and Environmental System procedures in place. The same were followed during all surveying tasks, which was undertaken by the company and its personnel.

Competent field survey staffs were deployed by GMPL to constantly monitor acquired data quality whilst the survey progressing, and was duly documented.

5.7 Demobilisation

Upon successful completion of topographic and bathymetric survey at Harnav dam with due, consent from Client Representative, the survey equipment on board were demobilised on 28 February 2021.

5.8 SURVEY DATA PROCESSING AND INTERPRETATION METHODS

5.8.1 General

The survey data was logged and was processed using the HYPACK Software. Position and depth data were processed and checked to ensure good data quality. The same was used for the automated and manual processing of logged data sets.

5.8.2 Navigation and Positioning

The measured offsets for various survey sensors used during the survey were entered into the navigation system and post processed using Hypack processing to enable track charts to be plotted and the 'corrected' navigation files to be integrated with other sensor data at a later stage.

5.8.3 Bathymetry Data Processing and Analysis

- The SBES bathymetry survey data was logged using HYPACK and further processed.
- Corrected SBES offset position (computed from vessel antenna) was merged into single beam data for true horizontal positioning.
- Velocity value 1510 m/s was used in the survey area.
- SBES data was further corrected for the transducer draft from water level.
- The depth sounding obtained from SBES were reduced to MSL with the help of observed water level in the reservoir The data was filtered, cleaned, and combined to create geographically positioned bathymetric data set that has been corrected for tides and sound speed.
- The data was filtered, cleaned, and combined to create geographically positioned bathymetric data set that has been corrected for tides and sound speed.
- The water level were observed during the entire period of survey. The details are as follows:-

Date	Time	Water Level (meters)
26/02/2021	0700	327.13
	1800	327.13
27/02/2021	0700	327.12
	1800	327.12
28/02/2021	0700	327.11
	1800	327.11

Table 5.8-1 WATER LEVELS

5.8.4 Topographic Data Processing and Analysis

The topographic survey data was cleaned and converted into xyz format. The converted data was merged with the bathymetric data using TIN module of Hypack software and Gridded data (25 x 25 m) was created. This data was used for volume calculations.

5.8.5 Preparation of Drawings

After the data processing phase, six drawings has been prepared for Harnav Reservoir, the details of which are presented in the table below:

Sr. No	Drawing Name	Description	Hard Copy format	Soft Copy format
1	P-SUR-004-Harnav-Bathy-01	Chart contains bathy , contour and cross section segments	1:5000	PDF & CAD
2	P-SUR-004-Harnav-Contour-01	Contour chart	1:7500	PDF & CAD
3	P-SUR-004-Harnav-Overview-01	Overview Map of Reservoir	Paper size A3	PDF & CAD
4	Area Capacity Curve Harnav -2021	Area Capacity curve of Reservoir	Paper size A3	PDF & CAD
5	Harnav Cross Sections	13 Cross Section at 100 m interval	Only soft copy	CAD
6	Harnav L- Section	L-Section of Reservoir	Paper size A3	CAD

Table 5.8-2 LIST OF CHARTS

6 DETAILED TOPOGRAPHIC AND BATHYMETRIC SURVEY RESULTS

6.1 General

Kindly refer to drawings in conjunction with the following:

Topographic and bathymetric data was reduced to the water level w.r.t MSL. All the data is plotted on scale of 1:5000 for Harnav reservoir.

The values depicted in the charts are the depths with respect to MSL.

- The Minimum elevation within Harnav DAM is 309.54 m above MSL and
- The Maximum depth within Harnav DAM is 11.58 m

6.2 Capacity and Area Calculation:

Hypack software's TIN (Triangulated Irregular Network) MODEL was used to calculate capacity and area of the reservoir at intervals of 10 cm. In addition, volume was also calculated using prismoidal formula as given below:

V=h/3{A1+A2+ Square Root (A1 * A2)}

where V is volume in M Cu. m between two levels,

h is difference between two level and

A1 & A2 is area in Sq. Km of successive levels

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
309.50	0.000	0.000	0.000	0.000	0.000	
309.60	0.000	0.000	0.000	0.000	0.000	
309.70	0.000	0.000	0.000	0.000	0.000	
309.80	0.000	0.000	0.000	0.000	0.001	
309.90	0.000	0.000	0.000	0.000	0.001	
310.00	0.000	0.000	0.000	0.000	0.002	
310.10	0.000	0.000	0.000	0.000	0.002	
310.20	0.001	0.000	0.001	0.001	0.003	
310.30	0.001	0.000	0.001	0.001	0.004	
310.40	0.002	0.000	0.002	0.002	0.006	
310.50	0.002	0.000	0.002	0.002	0.007	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
310.60	0.003	0.000	0.003	0.003	0.010	
310.70	0.004	0.000	0.004	0.004	0.014	
310.80	0.006	0.000	0.006	0.006	0.018	
310.90	0.008	0.000	0.008	0.008	0.021	
311.00	0.010	0.000	0.010	0.010	0.024	
311.10	0.013	0.000	0.013	0.013	0.027	
311.20	0.015	0.000	0.015	0.015	0.030	
311.30	0.019	0.000	0.019	0.019	0.032	
311.40	0.022	0.000	0.022	0.022	0.036	
311.50	0.026	0.000	0.026	0.026	0.039	
311.60	0.030	0.000	0.030	0.030	0.042	
311.70	0.034	0.000	0.034	0.034	0.045	
311.80	0.039	0.000	0.039	0.039	0.048	
311.90	0.044	0.000	0.044	0.044	0.052	
312.00	0.049	0.000	0.049	0.049	0.056	
312.10	0.055	0.000	0.055	0.055	0.060	
312.20	0.061	0.000	0.061	0.061	0.066	
312.30	0.068	0.000	0.068	0.068	0.073	
312.40	0.076	0.000	0.076	0.076	0.079	
312.50	0.084	0.000	0.084	0.084	0.085	
312.60	0.093	0.000	0.093	0.093	0.091	
312.70	0.102	0.000	0.102	0.102	0.097	
312.80	0.112	0.000	0.112	0.112	0.105	
312.90	0.123	0.000	0.123	0.123	0.112	
313.00	0.135	0.000	0.135	0.135	0.119	
313.10	0.147	0.000	0.147	0.147	0.127	
313.20	0.160	0.000	0.160	0.160	0.133	
313.30	0.173	0.000	0.173	0.173	0.139	
313.40	0.188	0.000	0.188	0.188	0.145	
313.50	0.202	0.000	0.202	0.202	0.152	
313.60	0.218	0.000	0.218	0.218	0.159	
313.70	0.234	0.000	0.234	0.234	0.166	
313.80	0.251	0.000	0.251	0.251	0.174	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
313.90	0.269	0.000	0.269	0.269	0.181	
314.00	0.287	0.000	0.287	0.287	0.188	
314.10	0.306	0.000	0.306	0.306	0.194	
314.20	0.326	0.000	0.326	0.326	0.200	
314.30	0.346	0.000	0.346	0.346	0.206	
314.40	0.367	0.000	0.367	0.367	0.212	
314.50	0.389	0.000	0.389	0.389	0.218	
314.60	0.411	0.000	0.411	0.411	0.224	
314.70	0.434	0.000	0.434	0.434	0.229	
314.80	0.457	0.000	0.457	0.457	0.235	
314.90	0.481	0.000	0.481	0.481	0.241	
315.00	0.505	0.000	0.505	0.505	0.247	
315.10	0.530	0.000	0.530	0.530	0.254	
315.20	0.556	0.000	0.556	0.556	0.261	
315.30	0.582	0.000	0.582	0.582	0.269	
315.40	0.609	0.000	0.609	0.609	0.276	
315.50	0.638	0.000	0.638	0.637	0.284	
315.60	0.666	0.000	0.666	0.666	0.291	
315.70	0.696	0.000	0.696	0.696	0.297	
315.80	0.726	0.000	0.726	0.726	0.303	
315.90	0.756	0.000	0.756	0.756	0.310	
316.00	0.788	0.000	0.788	0.788	0.316	
316.10	0.820	0.000	0.820	0.820	0.324	
316.20	0.852	0.000	0.852	0.852	0.331	
316.30	0.886	0.000	0.886	0.886	0.339	
316.40	0.920	0.000	0.920	0.920	0.346	
316.50	0.955	0.000	0.955	0.955	0.354	
316.60	0.991	0.000	0.991	0.991	0.362	
316.70	1.028	0.000	1.028	1.028	0.370	
316.80	1.065	0.000	1.065	1.065	0.379	
316.90	1.103	0.000	1.103	1.103	0.389	
317.00	1.143	0.000	1.143	1.143	0.398	
317.10	1.183	0.000	1.183	1.183	0.407	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
317.20	1.224	0.000	1.224	1.224	0.416	
317.30	1.266	0.000	1.266	1.266	0.424	
317.40	1.309	0.000	1.309	1.309	0.433	
317.50	**1.353**	**0.000**	**1.353**	**1.353**	**0.441**	**MDDL**
317.60	1.353	0.044	1.397	1.397	0.450	
317.70	1.353	0.090	1.443	1.443	0.458	
317.80	1.353	0.136	1.489	1.489	0.467	
317.90	1.353	0.183	1.536	1.536	0.476	
318.00	1.353	0.231	1.584	1.584	0.487	
318.10	1.353	0.281	1.634	1.634	0.499	
318.20	1.353	0.331	1.684	1.684	0.510	
318.30	1.353	0.383	1.736	1.735	0.520	
318.40	1.353	0.435	1.788	1.788	0.532	
318.50	1.353	0.489	1.842	1.842	0.544	
318.60	1.353	0.544	1.897	1.897	0.558	
318.70	1.353	0.601	1.954	1.953	0.571	
318.80	1.353	0.658	2.011	2.011	0.582	
318.90	1.353	0.717	2.070	2.070	0.593	
319.00	1.353	0.777	2.130	2.130	0.603	
319.10	1.353	0.838	2.191	2.190	0.613	
319.20	1.353	0.899	2.252	2.252	0.624	
319.30	1.353	0.962	2.315	2.315	0.635	
319.40	1.353	1.026	2.379	2.379	0.646	
319.50	1.353	1.092	2.445	2.444	0.658	
319.60	1.353	1.158	2.511	2.511	0.669	
319.70	1.353	1.225	2.578	2.578	0.681	
319.80	1.353	1.294	2.647	2.647	0.692	
319.90	1.353	1.364	2.717	2.717	0.704	
320.00	1.353	1.435	2.788	2.788	0.715	
320.10	1.353	1.507	2.860	2.860	0.727	
320.20	1.353	1.580	2.933	2.933	0.739	
320.30	1.353	1.655	3.008	3.008	0.753	
320.40	1.353	1.731	3.084	3.084	0.765	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
320.50	1.353	1.808	3.161	3.161	0.777	
320.60	1.353	1.886	3.239	3.239	0.790	
320.70	1.353	1.966	3.319	3.319	0.803	
320.80	1.353	2.047	3.400	3.400	0.816	
320.90	1.353	2.129	3.482	3.482	0.830	
321.00	1.353	2.213	3.566	3.566	0.843	
321.10	1.353	2.298	3.651	3.651	0.856	
321.20	1.353	2.384	3.737	3.737	0.870	
321.30	1.353	2.472	3.825	3.825	0.884	
321.40	1.353	2.561	3.914	3.914	0.899	
321.50	1.353	2.651	4.004	4.004	0.911	
321.60	1.353	2.743	4.096	4.096	0.924	
321.70	1.353	2.836	4.189	4.189	0.936	
321.80	1.353	2.930	4.283	4.283	0.945	
321.90	1.353	3.025	4.378	4.378	0.954	
322.00	1.353	3.121	4.474	4.474	0.963	
322.10	1.353	3.217	4.570	4.570	0.971	
322.20	1.353	3.315	4.668	4.668	0.982	
322.30	1.353	3.414	4.767	4.767	0.992	
322.40	1.353	3.514	4.867	4.866	1.001	
322.50	1.353	3.614	4.967	4.967	1.010	
322.60	1.353	3.715	5.068	5.068	1.019	
322.70	1.353	3.818	5.171	5.171	1.028	
322.80	1.353	3.921	5.274	5.274	1.038	
322.90	1.353	4.025	5.378	5.378	1.048	
323.00	1.353	4.131	5.484	5.484	1.058	
323.10	1.353	4.237	5.590	5.590	1.068	
323.20	1.353	4.344	5.697	5.697	1.079	
323.30	1.353	4.453	5.806	5.806	1.090	
323.40	1.353	4.562	5.915	5.915	1.101	
323.50	1.353	4.673	6.026	6.026	1.112	
323.60	1.353	4.785	6.138	6.138	1.124	
323.70	1.353	4.898	6.251	6.251	1.135	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
323.80	1.353	5.012	6.365	6.365	1.148	
323.90	1.353	5.127	6.480	6.480	1.162	
324.00	1.353	5.244	6.597	6.597	1.179	
324.10	1.353	5.363	6.716	6.716	1.193	
324.20	1.353	5.483	6.836	6.836	1.208	
324.30	1.353	5.604	6.957	6.957	1.222	
324.40	1.353	5.727	7.080	7.080	1.236	
324.50	1.353	5.852	7.205	7.205	1.250	
324.60	1.353	5.977	7.330	7.330	1.263	
324.70	1.353	6.104	7.457	7.457	1.277	
324.80	1.353	6.233	7.586	7.586	1.290	
324.90	1.353	6.362	7.715	7.715	1.304	
325.00	1.353	6.493	7.846	7.846	1.316	
325.10	1.353	6.625	7.978	7.978	1.328	
325.20	1.353	6.759	8.112	8.112	1.340	
325.30	1.353	6.893	8.246	8.246	1.353	
325.40	1.353	7.029	8.382	8.382	1.365	
325.50	1.353	7.167	8.520	8.520	1.379	
325.60	1.353	7.305	8.658	8.658	1.393	
325.70	1.353	7.445	8.798	8.798	1.406	
325.80	1.353	7.586	8.939	8.939	1.418	
325.90	1.353	7.729	9.082	9.082	1.430	
326.00	1.353	7.872	9.225	9.225	1.442	
326.10	1.353	8.017	9.370	9.370	1.461	
326.20	1.353	8.164	9.517	9.517	1.475	
326.30	1.353	8.312	9.665	9.665	1.485	
326.40	1.353	8.461	9.814	9.814	1.495	
326.50	1.353	8.611	9.964	9.964	1.503	
326.60	1.353	8.762	10.115	10.115	1.513	
326.70	1.353	8.914	10.267	10.267	1.521	
326.80	1.353	9.066	10.419	10.419	1.531	
326.90	1.353	9.220	10.573	10.573	1.540	
327.00	1.353	9.374	10.727	10.727	1.550	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
327.10	1.353	9.530	10.883	10.883	1.559	
327.20	1.353	9.686	11.039	11.039	1.570	
327.30	1.353	9.844	11.197	11.197	1.580	
327.40	1.353	10.002	11.355	11.355	1.590	
327.50	1.353	10.162	11.515	11.515	1.601	
327.60	1.353	10.322	11.675	11.675	1.611	
327.70	1.353	10.484	11.837	11.837	1.622	
327.80	1.353	10.647	12.000	12.000	1.634	
327.90	1.353	10.811	12.164	12.164	1.645	
328.00	1.353	10.976	12.329	12.329	1.657	
328.10	1.353	11.142	12.495	12.495	1.669	
328.20	1.353	11.310	12.663	12.663	1.682	
328.30	1.353	11.478	12.831	12.832	1.697	
328.40	1.353	11.649	13.002	13.002	1.712	
328.50	1.353	11.821	13.174	13.174	1.728	
328.60	1.353	11.994	13.347	13.348	1.744	
328.70	1.353	12.170	13.523	13.523	1.759	
328.80	1.353	12.346	13.699	13.699	1.773	
328.90	1.353	12.524	13.877	13.877	1.788	
329.00	1.353	12.704	14.057	14.057	1.803	
329.10	1.353	12.885	14.238	14.238	1.818	
329.20	1.353	13.067	14.420	14.420	1.833	
329.30	1.353	13.251	14.604	14.605	1.849	
329.40	1.353	13.437	14.790	14.790	1.866	
329.50	1.353	13.625	14.978	14.978	1.883	
329.60	1.353	13.814	15.167	15.167	1.902	
329.70	1.353	14.005	15.358	15.358	1.922	
329.80	1.353	14.198	15.551	15.551	1.945	
329.90	1.353	14.394	15.747	15.747	1.971	
330.00	1.353	14.592	15.945	15.946	1.999	
330.10	1.353	14.794	16.147	16.147	2.028	
330.20	1.353	14.998	16.351	16.351	2.058	
330.30	1.353	15.206	16.559	16.559	2.091	

Level (m)	Dead Storage Capacity (M Cu. M)	Live Storage Capacity (M Cu. M)	Gross Storage Capacity using TIN (M Cu. M)	Gross Storage Capacity using Prismoidal formula (M Cu. M)	Spread Area (Sq. Km)	Remarks
330.40	1.353	15.416	16.769	16.770	2.127	
330.50	1.353	15.631	16.984	16.984	2.162	
330.60	1.353	15.849	17.202	17.202	2.196	
330.70	1.353	16.070	17.423	17.423	2.231	
330.80	1.353	16.295	17.648	17.648	2.266	
330.90	1.353	16.523	17.876	17.877	2.306	
331.00	1.353	16.756	18.109	18.109	2.344	
331.10	1.353	16.992	18.345	18.346	2.383	
331.20	1.353	17.233	18.586	18.586	2.424	
331.30	1.353	17.477	18.830	18.830	2.466	
331.40	1.353	17.726	19.079	19.079	2.507	
331.50	1.353	17.979	19.332	19.332	2.551	
331.60	1.353	18.236	19.589	19.589	2.595	
331.70	1.353	18.497	19.850	19.851	2.634	
331.80	1.353	18.763	20.116	20.116	2.671	
331.90	1.353	19.031	20.384	20.385	2.703	
332.00	**1.353**	**19.303**	**20.656**	**20.656**	**2.732**	**FRL**
332.10	1.353	19.578	20.931	20.931	2.763	
332.20	1.353	19.856	21.209	21.209	2.798	
332.30	1.353	20.137	21.490	21.491	2.836	
332.40	1.353	20.423	21.776	21.777	2.882	
332.50	1.353	20.714	22.067	22.067	2.936	
332.60	1.353	21.011	22.364	22.364	2.995	
332.70	1.353	21.313	22.666	22.666	3.052	
332.80	1.353	21.621	22.974	22.974	3.107	
332.90	1.353	21.934	23.287	23.288	3.160	
333.00	1.353	22.253	23.606	23.606	3.207	
333.10	1.353	22.576	23.929	23.929	3.251	
333.20	1.353	22.903	24.256	24.256	3.294	
333.30	1.353	23.234	24.587	24.588	3.335	
333.35	**1.353**	**23.402**	**24.755**	**24.755**	**3.355**	**HFL**

Table 6.2-1 Capacity and Area

6.3 Comparative Statement of Harnav Reservoir

Elevation	Original		As per 2021		Remark
	Area (Sq. Km)	Gross Capacity M. Cu. m)	Area (Sq. Km)	Gross Capacity M. Cu. m)	
315.00	0.264	0.816	0.247	0.505	
316.00	0.323	1.108	0.316	0.788	
317.00	0.390	1.395	0.398	1.143	
317.50	**0.446**	**1.700**	**0.441**	**1.353**	**MDDL**
318.00	0.502	1.975	0.487	1.584	
319.00	0.616	2.495	0.603	2.130	
320.00	0.728	3.045	0.715	2.788	
321.00	0.838	3.939	0.843	3.566	
322.00	0.949	4.821	0.963	4.474	
323.00	1.060	5.724	1.058	5.484	
324.00	1.206	6.999	1.179	6.597	
325.00	1.353	8.214	1.316	7.846	
326.00	1.499	9.549	1.442	9.225	
327.00	1.662	11.287	1.550	10.727	
328.00	1.826	13.025	1.657	12.329	
329.00	1.989	14.764	1.803	14.057	
330.00	2.221	17.068	1.999	15.945	
331.00	2.454	19.373	2.344	18.109	
332.00	**2.686**	**21.678**	**2.732**	**20.656**	**FRL**

Table 6.3-1 COMPARATIVE STATEMENT OF HARNAV RESERVOIR

6.4 Gross Capacity in M Cu. m of the Reservoir - Year 2020:

RL (m)	0	0.1	0.2	0.3	0.35	0.4	0.5	0.6	0.7	0.8	0.9
309							0.000	0.000	0.000	0.000	0.000
310	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.004	0.006	0.008
311	0.010	0.013	0.015	0.019	0.020	0.022	0.026	0.030	0.034	0.039	0.044
312	0.049	0.055	0.061	0.068	0.072	0.076	0.084	0.093	0.102	0.112	0.123
313	0.135	0.147	0.160	0.173	0.180	0.188	0.202	0.218	0.234	0.251	0.269
314	0.287	0.306	0.326	0.346	0.357	0.367	0.389	0.411	0.434	0.457	0.481
315	0.505	0.530	0.556	0.582	0.596	0.609	0.638	0.666	0.696	0.726	0.756
316	0.788	0.820	0.852	0.886	0.903	0.920	0.955	0.991	1.028	1.065	1.103
317	1.143	1.183	1.224	1.266	1.287	1.309	**1.353**	1.397	1.443	1.489	1.536
318	1.584	1.634	1.684	1.736	1.762	1.788	1.842	1.897	1.954	2.011	2.070
319	2.130	2.191	2.252	2.315	2.347	2.379	2.445	2.511	2.578	2.647	2.717
320	2.788	2.860	2.933	3.008	3.046	3.084	3.161	3.239	3.319	3.400	3.482
321	3.566	3.651	3.737	3.825	3.869	3.914	4.004	4.096	4.189	4.283	4.378
322	4.474	4.570	4.668	4.767	4.817	4.867	4.967	5.068	5.171	5.274	5.378
323	5.484	5.590	5.697	5.806	5.860	5.915	6.026	6.138	6.251	6.365	6.480
324	6.597	6.716	6.836	6.957	7.019	7.080	7.205	7.330	7.457	7.586	7.715
325	7.846	7.978	8.112	8.246	8.314	8.382	8.520	8.658	8.798	8.939	9.082
326	9.225	9.370	9.517	9.665	9.739	9.814	9.964	10.115	10.267	10.419	10.573
327	10.727	10.883	11.039	11.197	11.276	11.355	11.515	11.675	11.837	12.000	12.164
328	12.329	12.495	12.663	12.831	12.917	13.002	13.174	13.347	13.523	13.699	13.877

RL (m)	0	0.1	0.2	0.3	0.35	0.4	0.5	0.6	0.7	0.8	0.9
329	14.057	14.238	14.420	14.604	14.697	14.790	14.978	15.167	15.358	15.551	15.747
330	15.945	16.147	16.351	16.559	16.664	16.769	16.984	17.202	17.423	17.648	17.876
331	18.109	18.345	18.586	18.830	18.954	19.079	19.332	19.589	19.850	20.116	20.384
332	**20.656**	20.931	21.209	21.490	21.633	21.776	22.067	22.364	22.666	22.974	23.287
333	23.606	23.929	24.256	24.587	**24.755**						

Table 6.4-1 GROSS STORAGE CAPACITY IN M cu. m YEAR -2021

Note: Gross storage capacity for FRL at 332 m is 20.656 M Cu. m, dead storage at 317.50 m is 1.353 M Cu. m and HFL at 333.35 m is 24.755 M Cu. m.

6.5 Live Storage Capacity in M Cu. m of the Reservoir - Year 2021:

RL (m)	0	0.1	0.2	0.3	0.35	0.4	0.5	0.6	0.7	0.8	0.9
317							0.000	0.044	0.090	0.136	0.183
318	0.231	0.281	0.331	0.383	0.409	0.435	0.489	0.544	0.601	0.658	0.717
319	0.777	0.838	0.899	0.962	0.994	1.026	1.092	1.158	1.225	1.294	1.364
320	1.435	1.507	1.580	1.655	1.693	1.731	1.808	1.886	1.966	2.047	2.129
321	2.213	2.298	2.384	2.472	2.516	2.561	2.651	2.743	2.836	2.930	3.025
322	3.121	3.217	3.315	3.414	3.464	3.514	3.614	3.715	3.818	3.921	4.025
323	4.131	4.237	4.344	4.453	4.507	4.562	4.673	4.785	4.898	5.012	5.127
324	5.244	5.363	5.483	5.604	5.666	5.727	5.852	5.977	6.104	6.233	6.362
325	6.493	6.625	6.759	6.893	6.961	7.029	7.167	7.305	7.445	7.586	7.729
326	7.872	8.017	8.164	8.312	8.386	8.461	8.611	8.762	8.914	9.066	9.220
327	9.374	9.530	9.686	9.844	9.923	10.002	10.162	10.322	10.484	10.647	10.811
328	10.976	11.142	11.310	11.478	11.564	11.649	11.821	11.994	12.170	12.346	12.524
329	12.704	12.885	13.067	13.251	13.344	13.437	13.625	13.814	14.005	14.198	14.394
330	14.592	14.794	14.998	15.206	15.311	15.416	15.631	15.849	16.070	16.295	16.523
331	16.756	16.992	17.233	17.477	17.601	17.726	17.979	18.236	18.497	18.763	19.031
332	**19.303**	19.578	19.856	20.137	20.280	20.423	20.714	21.011	21.313	21.621	21.934
333	22.253	22.576	22.903	23.234	**23.402**						

Table 6.5-1 LIVE STORAGE CAPACITY IN M Cu. m. YEAR -2021

Note: Live storage capacity for FRL at 332 m is 19.303 M Cu. m and HFL at 333.35 m is 23.402 M Cu. m.

6.6 Spread Area in Sq. Km of the Reservoir - Year 2021:

RL (m)	0	0.1	0.2	0.3	0.35	0.4	0.5	0.6	0.7	0.8	0.9
309							0.000	0.000	0.000	0.001	0.001
310	0.002	0.002	0.003	0.004	0.005	0.006	0.007	0.010	0.014	0.018	0.021
311	0.024	0.027	0.030	0.032	0.034	0.036	0.039	0.042	0.045	0.048	0.052
312	0.056	0.060	0.066	0.073	0.076	0.079	0.085	0.091	0.097	0.105	0.112
313	0.119	0.127	0.133	0.139	0.142	0.145	0.152	0.159	0.166	0.174	0.181
314	0.188	0.194	0.200	0.206	0.209	0.212	0.218	0.224	0.229	0.235	0.241
315	0.247	0.254	0.261	0.269	0.273	0.276	0.284	0.291	0.297	0.303	0.310
316	0.316	0.324	0.331	0.339	0.343	0.346	0.354	0.362	0.370	0.379	0.389
317	0.398	0.407	0.416	0.424	0.428	0.433	0.441	0.450	0.458	0.467	0.476
318	0.487	0.499	0.510	0.520	0.526	0.532	0.544	0.558	0.571	0.582	0.593
319	0.603	0.613	0.624	0.635	0.640	0.646	0.658	0.669	0.681	0.692	0.704
320	0.715	0.727	0.739	0.753	0.759	0.765	0.777	0.790	0.803	0.816	0.830
321	0.843	0.856	0.870	0.884	0.891	0.899	0.911	0.924	0.936	0.945	0.954
322	0.963	0.971	0.982	0.992	0.997	1.001	1.010	1.019	1.028	1.038	1.048
323	1.058	1.068	1.079	1.090	1.095	1.101	1.112	1.124	1.135	1.148	1.162
324	1.179	1.193	1.208	1.222	1.229	1.236	1.250	1.263	1.277	1.290	1.304
325	1.316	1.328	1.340	1.353	1.359	1.365	1.379	1.393	1.406	1.418	1.430
326	1.442	1.461	1.475	1.485	1.490	1.495	1.503	1.513	1.521	1.531	1.540
327	1.550	1.559	1.570	1.580	1.585	1.590	1.601	1.611	1.622	1.634	1.645
328	1.657	1.669	1.682	1.697	1.705	1.712	1.728	1.744	1.759	1.773	1.788

RL (m)	0	0.1	0.2	0.3	0.35	0.4	0.5	0.6	0.7	0.8	0.9
329	1.803	1.818	1.833	1.849	1.857	1.866	1.883	1.902	1.922	1.945	1.971
330	1.999	2.028	2.058	2.091	2.109	2.127	2.162	2.196	2.231	2.266	2.306
331	2.344	2.383	2.424	2.466	2.487	2.507	2.551	2.595	2.634	2.671	2.703
332	**2.732**	2.763	2.798	2.836	2.858	2.882	2.936	2.995	3.052	3.107	3.160
333	3.207	3.251	3.294	3.335	**3.355**						

Table 6.6-1 SPREAD AREA IN SQ. KM YEAR -2021

Note: Spread Area for FRL at 332 m is 2.732 Sq. Km and HFL at 333.35 m is 3.355 Sq. Km.

6.7 Sediment Analysis:

6.7.1 Observed Rate of Sedimentation

The reservoir was impounded during the year 1990. As per survey of the year 1990, total area of reservoir at FRL 332 m was 2.686. Km, corresponding storage capacity was 21.678 M Cu. m, and Dead storage at 317.50 m was 1.7 M Cu. m.

The reservoir was recently surveyed by means of integrated bathymetric and topographic survey in year 2021. As per survey recent survey, total area of reservoir at FRL 332 m is 2.732 Sq. Km, corresponding storage capacity is 20.656 M Cu. m and Dead storage at 317.50 m is 1.353 M Cu. m.

The rate of siltation in the reservoir (up to FRL 332 m) during the last 45 years (1990-2021), was found to be 0.033 M Cu. m / year.

Original Reservoir data:

Year of Impounding : 1990
Catchment Area : 116 Sq. Km
Surface area at 332 m : 2.686 Sq. Km
Live storage at 332 m : 19.97 M Cu. m
Dead storage at 317.50 m : 1.7 M Cu. m
Gross storage at 332 : 21.67 M Cu. m

Rate of Sedimentation (at FRL 332) with respect to impounding year 1990													
Sr. No	**Year of Survey**	**Capacity in M Cu. m**			**Period in years**	**Silt Deposited in M Cu. m**	**Silt Rate in M Cu. m/year**	**Loss in Capacity in M Cu. m and percentage**			**Silt Index ham/100 Sq. Km/Yr.**	**Annual % loss**	**Remarks**
		Dead	**Live**	**Gross**				**Dead**	**Live**	**Gross**			
1	1990	1.7	19.97	21.67	-	-	-	-	-	-	-	-	
2	2021 (Hydrographic survey)	1.353	19.303	20.656	31	1.014	0.033	0.347 20.41%	0.667 3.34%	1.014 4.68%	2.82	0.15%	**Significant Category**

Table 6.6-2 RATE OF SEDIMENTATION

<u>According to IS -12182 (1987)</u>

Annual % loss	**-**	**Class of Reservoir**
Up to 0.1	-	Insignificant
0.1 to 0.5	-	Significant
Above 0.5	-	Serious

Rate of Silt = Loss in Gross Capacity in M Cu. m/No of Years
Silt Index = (Silt Rate/Catchment area) x 10000
Annual % Loss = Loss in % of Gross Capacity/No of years

6.8 Conclusion

- By above table we can conclude that the capacity of reservoir is decreased due to deposition of sediments in the reservoir.
- The annual percentage loss from survey of the year 2021 is 0.15% for FRL 332 m.
- Reservoir is classified as "**Significant category**" as per IS 12182-1987 and requires actions to control deposition of sediments in the reservoir.

6.9 Methods for controlling the sedimentation

According to IS-6518:2017 there are several factors involved in controlling sedimentation in reservoirs and they relate to aspects on,

a) Design of reservoir.
b) Control of sediment inflow.
c) Control of sediment deposition.
d) Removal of sediments.

All these aspects are to be simultaneously taken note of and appropriate measures be adopted.

6.9.1 Design of Reservoirs

The capacity of reservoirs is governed by a number of factors which are covered in IS 5477 (Parts 1 to 4). From the point of view of sediment deposition, the following points may be given due consideration:

a) The sediment yield which depends on the topographical, geological and geomorphological set up, meteorological factors, land use/land cover, intercepting tanks, etc.;
b) Sediment delivery characteristics of the channel system;
c) The efficiency of the reservoir as sediment trap;
d) The ratio of capacity of reservoir to the inflow;
e) Configuration of reservoir;
f) Method of operation of reservoir; and
g) Provisions for silt exclusion.

- The rate of sediment delivery increases with the quantum of discharge.
- The percentage of sediment trapped by a reservoir with a given drainage area increases with the increased capacity. In some cases an increased capacity will however, result in greater loss of water due to evaporation. However, with the progress of sedimentation, there is decrease of storage capacity which in turn lowers the trap efficiency of the reservoir.
- The capacity of the reservoir and the size and characteristics of the reservoir and its drainage area are the most important factors governing the annual rate of accumulation of sediment. Periodical reservoir sedimentation surveys provide guidance on the rate of sedimentation. In the absence of observed data for the reservoir concerned, data from other reservoirs of similar capacity and catchment characteristics may be adopted.
- Sedimentation takes place not only in the dead storage but also in the live storage space in the reservoir. The practice for design of reservoir is to use the observed suspended sediment data available from key hydrologica1 networks and also the data available from hydrographic surveys of other reservoirs in the same region.

This data may be used to simulate sedimentation status over a period of reservoir life as mentioned in IS 12182.

- Raising the Dam at Periodic Intervals:

Engineering economic analysis of some reservoir projects probably would show that it is cheaper to build a substantially lower dam initially, and to raise it at intervals unti1 its ultimate height for the given original capacity so that long useful life may result. Stage-wise construction also provides lower trapping efficiency and less evaporation in the initial stages.

However, this method may not be feasible in all the existing dams. Wherever this method is contemplated, proper consideration should be given on the strength.

6.9.2 Control of Sediment Inflow

There are many methods for controlling sediment inflows and they can be divided as follows:

1. Watershed management/soil conservation measures to check production and transport of sediment in the catchment area

1.1. The engineering methods

1.1.1. Check Dams

a) They help to arrest degradation of stream bed thereby arresting the slope failure; and

b) They reduce the velocity of stream flow, thereby causing the deposition of the sediment load.

Check dams become necessary, where the channel gradients are steep and there is a heavy inflow of sediment from the watershed. They are constructed of local material like earth, rock, timber, etc. These are suitable for small catchment varying in size from 40 to 400 hectares. It is necessary to provide small check dams on the subsidiary streams flowing into the main streams besides the check dams in the main stream. Proper consideration should be given to the number and location of check dams required. It is preferable to minimize the height of the check dams. If the stream has, a very-steep slope, it is desirable to start with a smaller height for the check dams than may ultimately be necessary.

Check dams may generally cost more per unit of storage than the reservoirs they protect. Therefore, it may not always be possible to adopt them as a primary method of sediment control in new reservoirs. However, feasibility of providing check dams at later date should not be overlooked while planning the construction of a new reservoir

1.1.2. Contour Bunding and Trenching

These are important methods of controlling soil erosion on the hills and sloping lands, where gradients of cultivated fields or terraces are flatter, say up to 10 percent. By these methods the hill side is split up into small compartments on which the rain is retained and surface run-off is modified with prevention of soil erosion. In addition to contour bunding, side trenching is also provided as per requirement.

1.1.3. Gully Plugging

This is done by small rock fill dams. These dams will be effective in filling up the gullies with sediment coming from the upstream of the catchment and also prevent further widening of the gully.

1.1.4. Bank Protection

This is achieved by terracing, revetment, retaining walls, gabions and spurs.

1.2. Agronomy

The agronomic measures include establishment of vegetative screen, contour farming, strip cropping and crop rotation.

1.3. Forestry

Forestry measures include forest conservancy, control on grazing, lumbering, operations and forest fires along with management and protection of forest plantations.

2. Preventive measures to check inflow of sediment into the reservoir

2.1. Restricting the waste/sediment entering into the reservoirs due to agricultural and infrastructural activities surrounding the submergence.

2.2. Construction of by-pass channels or conduits.

The various methods in this category require the construction of some type of diversion dam or weir at the head of the reservoir basin, and a canal, tunnel or conduit leading around the reservoir to a point below the dam where the flow may re-enter the main channels. In such cases the flood flows of sediment laden water are by-passed to the downstream of the dam. In some cases where topography permits construction of new off channel reservoirs can be considered. These reservoirs will invariably have a forebay and check dam on the upstream for trapping the sediment. The stored water in the fore bay is led to the reservoir and the sediment trapped is flushed through by by-pass channel/ conduit/tunnel to the main channel downstream of the dam.

6.9.3 Control of Sediment Deposition

The deposition of sediment in a reservoir may be controlled to a certain extent by designing and operating gates or other outlets in the dam in such a manner as to permit selective withdrawals of water having a higher than average sediment content. The suspended sediment content of the water in reservoirs is higher during and just after flood flow. Thus, more the water wasted at such times, the smaller will be the percentage of the total sediment load to settle into permanent deposits. There are generally three methods:

- **Density current**

Water at various levels of a reservoir often contains radically different concentrations of suspended sediment particularly during and after flood flows. If all wastewater could be withdrawn at those levels where the concentration is highest, a significant amount of sediment might be removed from the reservoir. Because a submerged outlet draws water towards it from all directions, the vertical dimension of the opening should be small with respect to the thickness of the layer and the rate of withdrawal also should be low.

- **Waste-water release**

Controlling the sedimentation by controlling waste- water release is obviously possible only when water can be or should be wasted. This method is applicable only when a reservoir is of such size that a small part of large flood flows will fill it.

In the design of the dam, sediment may be passed through or over it as an effective method of silt control by placing a series of outlets at various elevations. The percentage of total sediment load that might be ejected from the reservoir through proper gate control will differ greatly with different locations. It is probable that as much as 20 percent of the sediment inflow could be passed through many reservoirs by venting through outlets designed and controlled.

- **Scouring Sluicing**

This method is somewhat similar to both the control of waste-water release and the draining and flushing methods

The distinctions amongst them are the following:

a) The waste-water release method ejects sediment laden flood flows through deep spillway gates or large under-sluices at the rate of discharge that prevents sedimentation.

b) Drainage and flushing method involves the slow release of stored water from the reservoir through small gates or valves making use of normal or low flow to entrain and carry the sediment, and

c) Scouring sluicing depends for its efficiency on either the scouring action exerted by the sudden rush of impounded water under a high head through under-sluices or on the scouring action of high flood discharge coming into the reservoir

Scouring sluicing method can be used in the following:

i. Small power dams that depend to a great extent on pondage but not on storage;
ii. Small irrigation reservoirs, where only a small fraction of the total annual flow can be stored;
iii. Any reservoir in narrow channels, gorges, etc, where water wastage can be afforded; and
iv. When the particular reservoir under treatment is a unit in an interconnected system so that the other reservoirs can supply the water needed.

6.9.4 Removal of Sediment Deposit

The most practical means of maintaining the storage capacity are those designed to prevent accumulation of permanent deposits as the removal operations are extremely expensive, unless the material removed is usable. Therefore, the redemption of lost storage by removal should be adopted as a last resort. The removal of sediment deposit implies in general, that the deposits are sufficiently compacted or consolidated to act as a solid and, therefore, are unable to flow along with the water. The removal of sediment deposits may be accomplished by a variety of mechanical and hydraulic or methods, such as excavation, dredging, siphoning, draining, flushing, flood sluicing, and sluicing aided by such measures as hydraulic or mechanical agitation or blasting of the sediment. The excavated sediments may be suitably disposed off so that, these do not find the way again in the reservoir.

1. Excavation

The method involves draining most of or all the water in the basin and removing the sediment by hand or power operated shovel, dragline scraper or other mechanical means.

The excavation of silt and clay, which constitute most of the material in larger reservoirs, is more difficult than the excavation of sand and gravel. Fine-textured sediment cannot be excavated easily from larger reservoirs unless it is relatively fluid or relatively compact.

2. Dredging

This involves the removal of deposits from the bottom of a reservoir and their conveyance to some other point by mechanical or hydraulic means, while water storage is being maintained.

Dredging practices are grouped as:

a) Mechanical dredging by bucket, ladder, etc;
b) Suction dredging with floating pipeline and a pump usually mounted on a barge; and
c) Siphon dredging with a floating pipe extending over the dam or connected to an opening in the dam and usually with a pump on a barge.

NOTES

1) Practicality of the two methods, namely, excavation and dredging, requires to be carefully considered in any particular case.
2) Suitable measures to prevent deposition of the dredged silt in the natural channel where it is discharged need to be adopted.

3. Draining and Flushing

The method involves relatively slow release of all stored water in a reservoir through gates or valves located near bottom of the dam and the maintenance thereafter of open outlets for a shorter or longer period during which normal stream flow cuts into or directed against the sediment deposits. Therefore, this method may be adopted in flood control reservoirs.

4. Sluicing with Controlled Water

This method differs from the flood sluicing in that the controlled water supply permits choosing the time of sluicing more advantageously and that the water may be directed more effectively against the sediment deposits. While the flood sluicing depends either on the occurrence of flood or on being able to release rapidly all of a full or nearly full supply of water in the main reservoir is empty. The advantage of this method is that generally more sediment can be removed per unit of water used than in flood scouring or draining and flushing.

5. Sluicing with Hydraulic and Mechanical Agitation

Methods that stir up break up or move deposits of sediment into a stream current flowing through a drained reservoir basin or into a lake current moving through and out of a full reservoir will tend to make the removal of sediment from the reservoir more complete. Wherever draining, flushing or sluicing appear to be warranted, the additional use of hydraulic means for stirring up the sediment deposits, or sloughing them off, into a stream flowing through the reservoir basin should be considered. It has, however, limited application.

6.10 Area – Capacity – Curve of Harnav Dam:

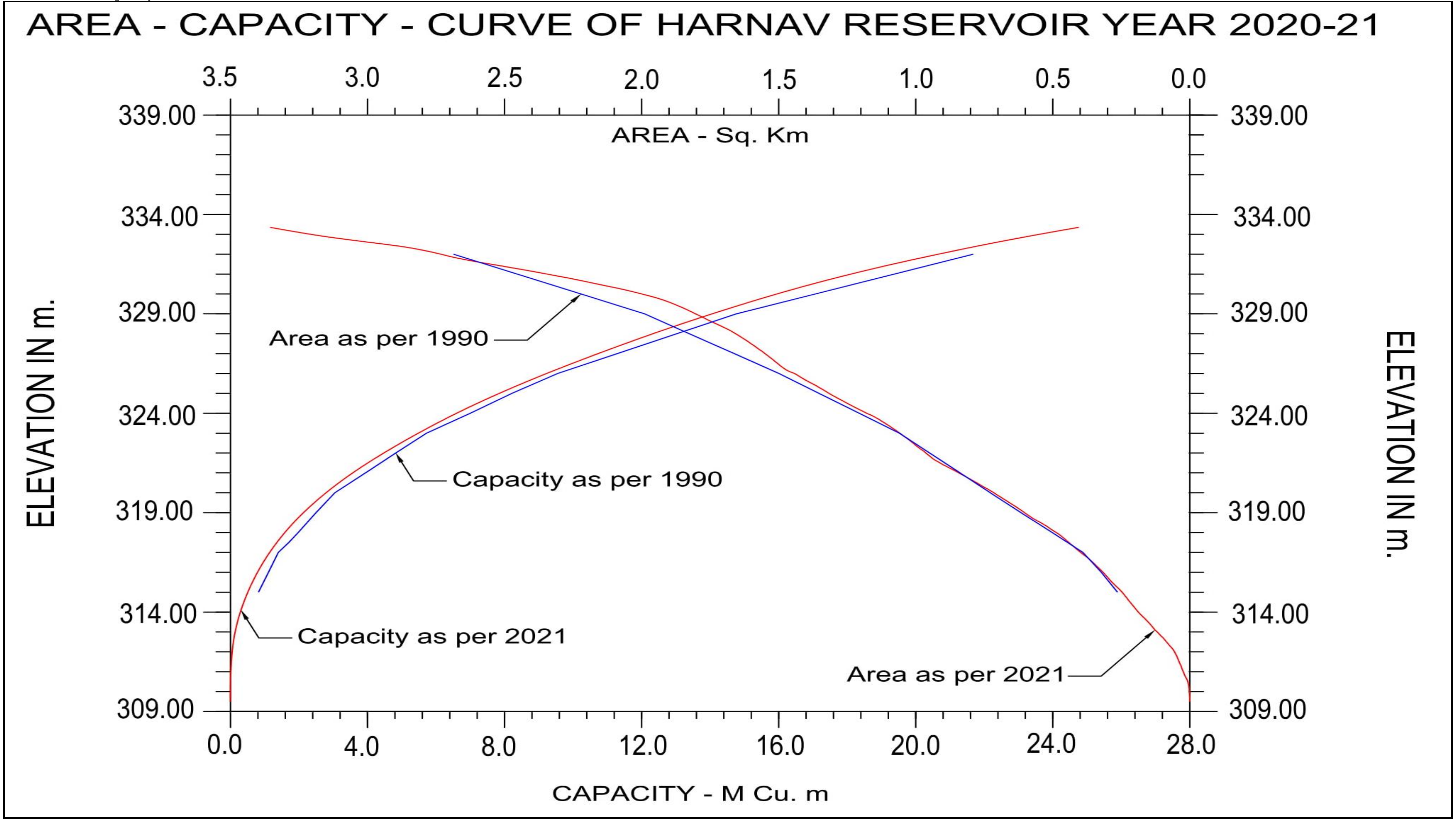


Figure 6.10-1 AREA – CAPACITY - CURVE

6.11 Segment, Contour, Wire Frame Map and L Section:

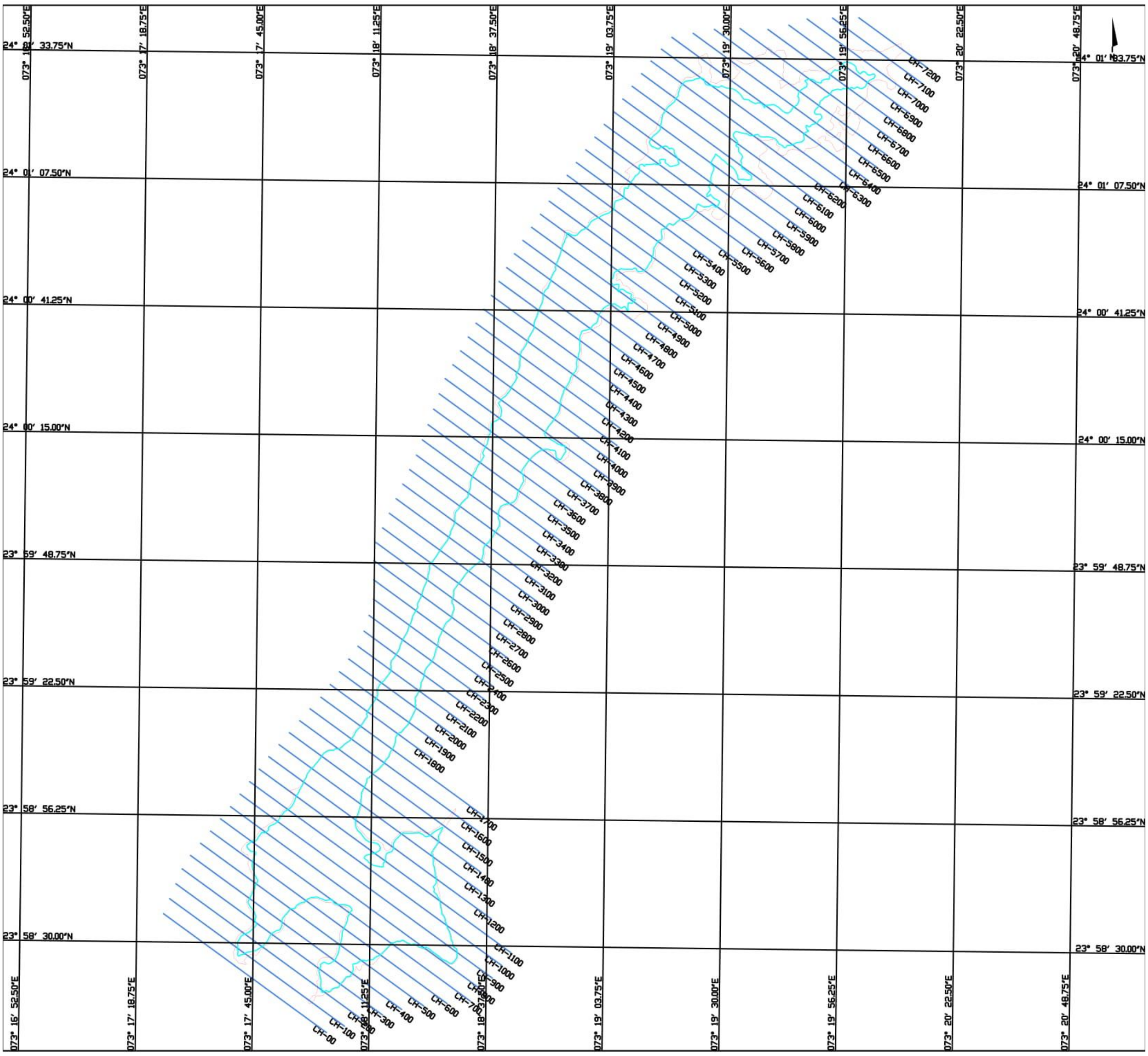


Figure 6.11-1 SEGMENT MAP FOR CROSS SECTION

Cross sections showing bed profile at 100m interval were prepared and are provided as soft copy in CD/Hard Disc. Total 72 cross section profiles were prepared.

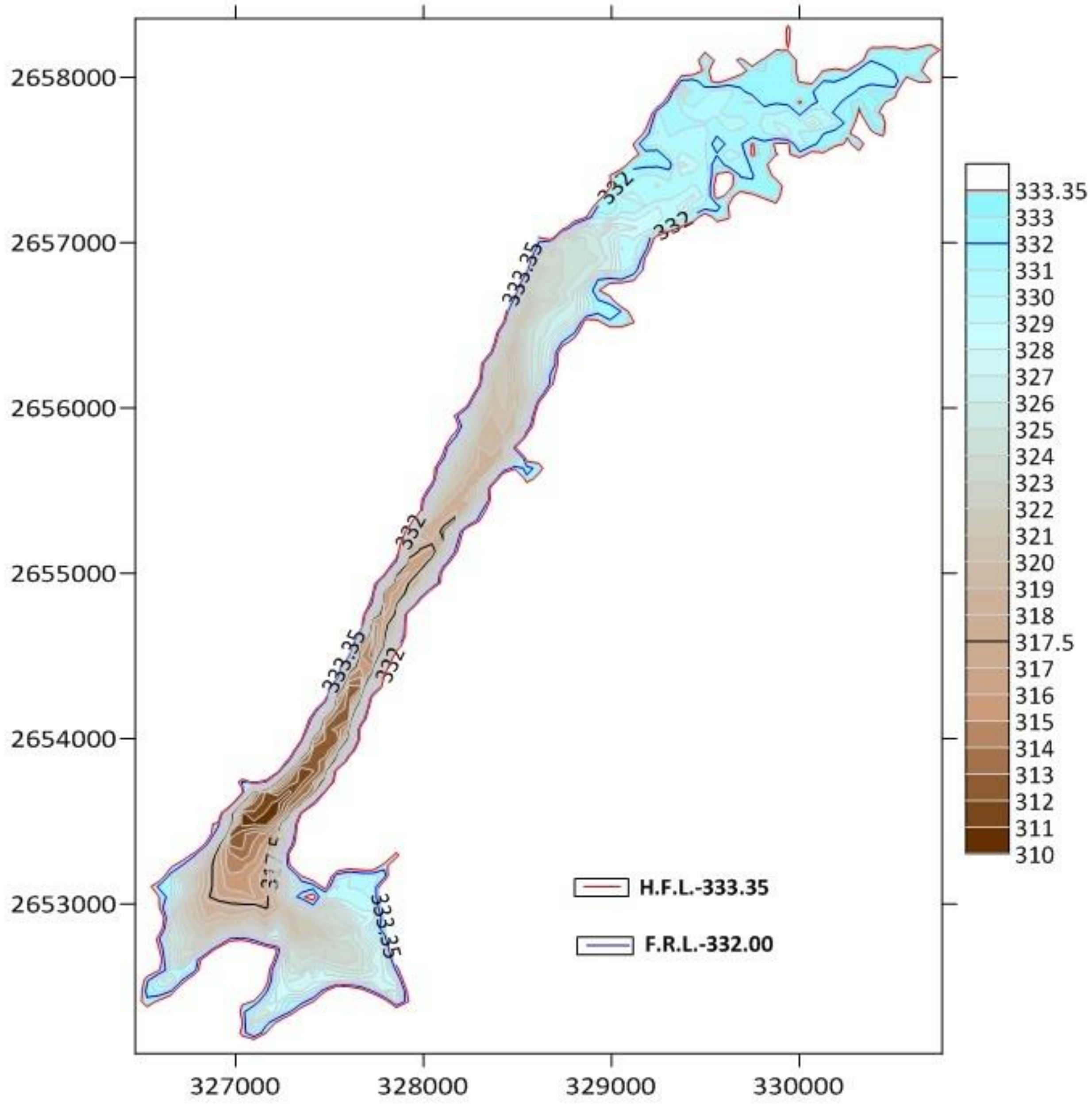


Figure 6.11-2 CONTOUR MAP

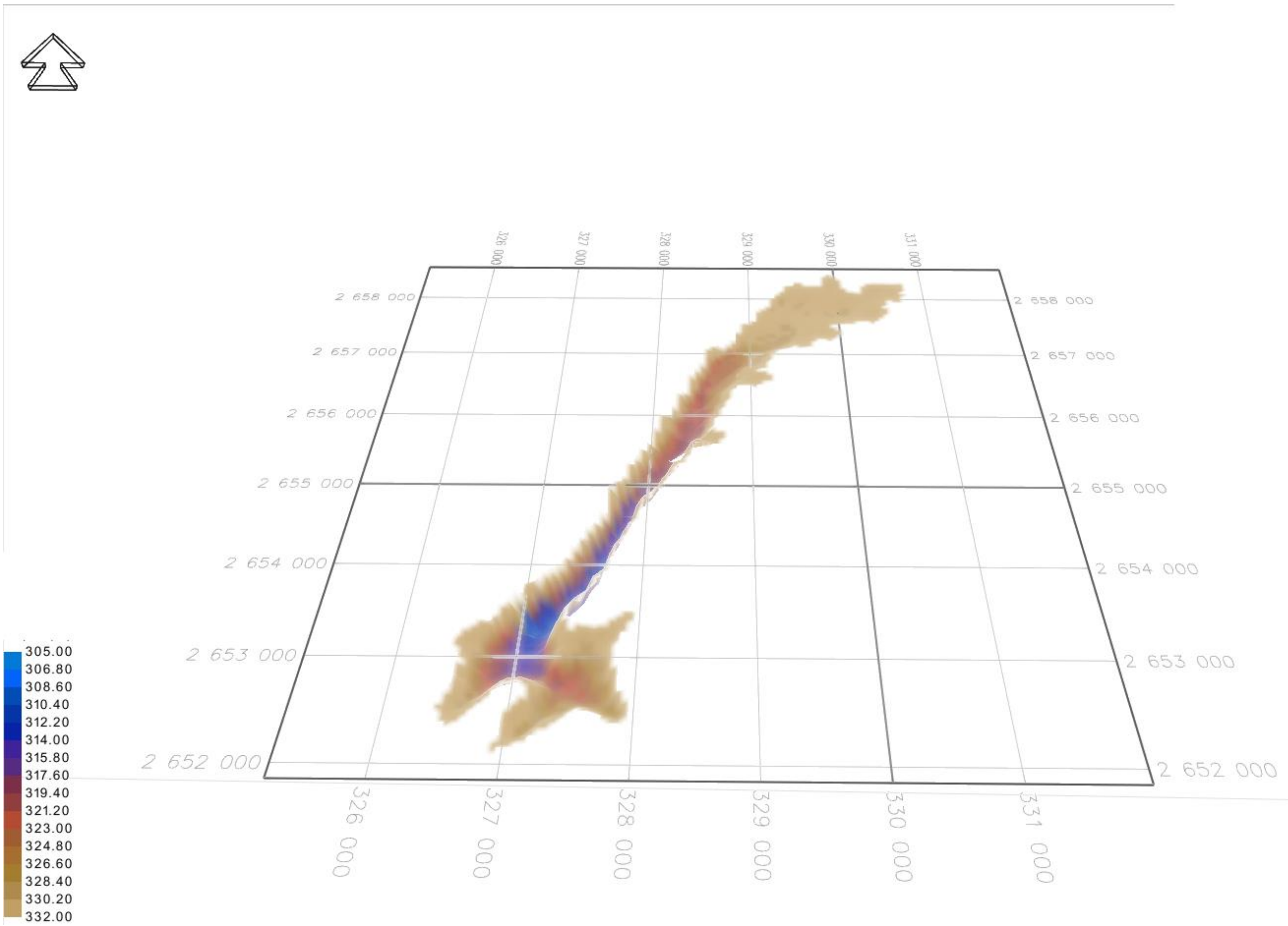


Figure 6.11-3 WIRE FRAME MAP

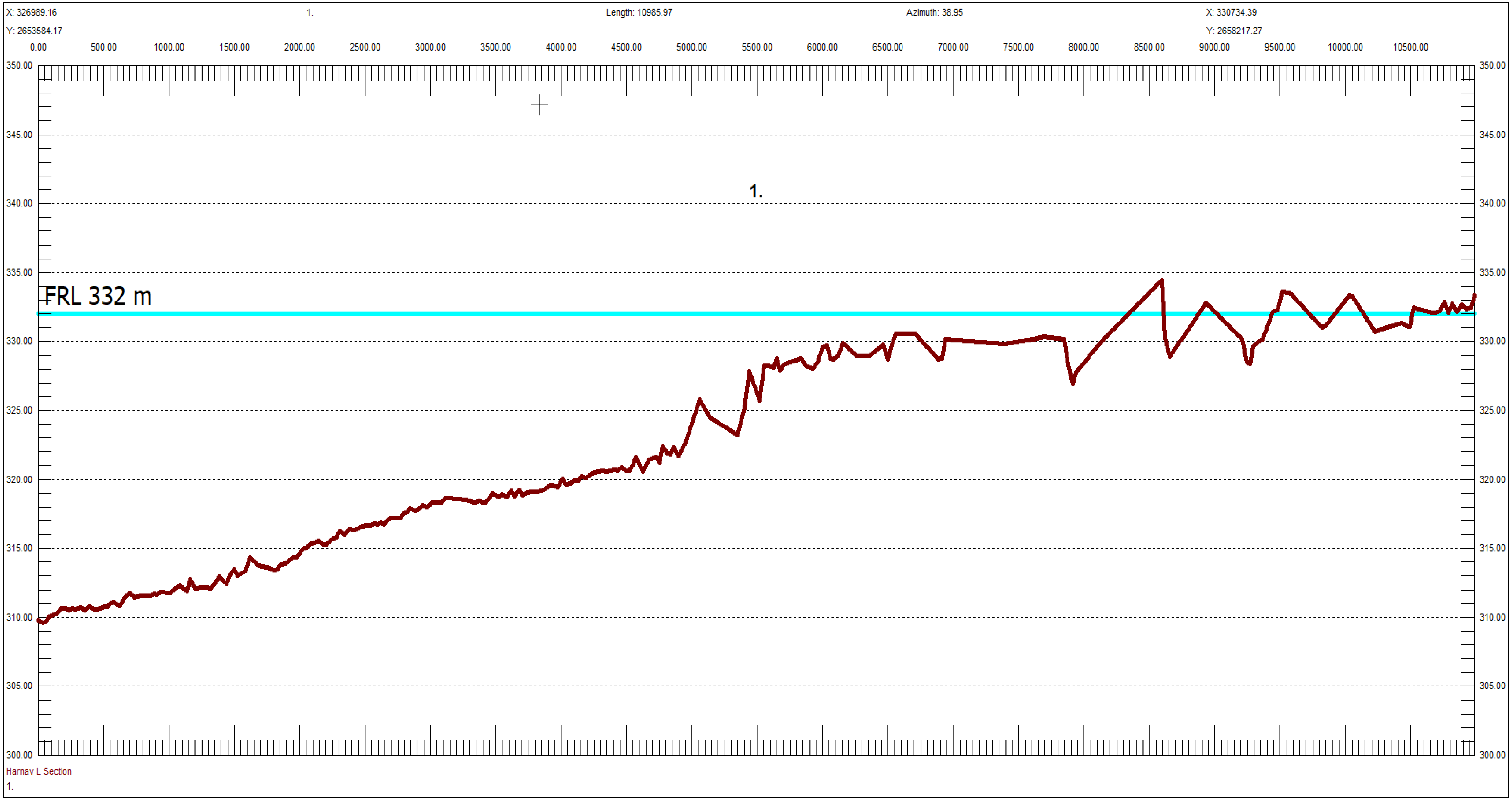


Figure 6.11-4 L SECTION

7 DGPS OBSERVATION REPORT

CSRS-PPP 3.49.0 (2021-01-25)

HARN_25032021_115452.21O
HARN

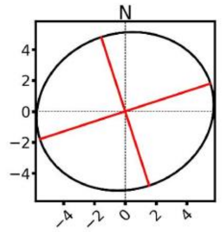
Data Start	**Data End**	**Duration of Observations**	
2021-03-25 03:54:55.00	2021-03-25 07:58:50.00	4:03:55	
Processing Time		**Product Type**	
09:17:23 UTC 2021/03/25		NRCan Ultra-rapid	
Observations	**Frequency**	**Mode**	
Phase and Code	Double	Static	
Elevation Cut-Off	**Rejected Epochs**	**Fixed Ambiguities**	**Estimation Steps**
7.5 degrees	0.00 %	97.48 %	5.00 sec
Antenna Model	**APC to ARP**	**ARP to Marker**	
TIAPENG6	L1 = 0.096 m L2 = 0.091 m	H:1.874m / E:0.000m / N:0.000m	

(APC = antenna phase center; ARP = antenna reference point)

Estimated Position for HARN_25032021_115452.21O

	Latitude (+n)	Longitude (+e)	Ell. Height
ITRF14 (2021.2)	23° 59' 4.98974"	73° 17' 56.18018"	292.843 m
Sigmas(95%)	0.004 m	0.005 m	0.019 m
A priori*	23° 59' 4.99962"	73° 17' 56.18034"	294.969 m
Estimated – A priori	-0.304 m	-0.005 m	-2.126 m

95% Error Ellipse (mm)
semi-major: 6 mm
semi-minor: 5 mm
semi-major azimuth: 72° 0' 51.16"



UTM (North)
Zone 43

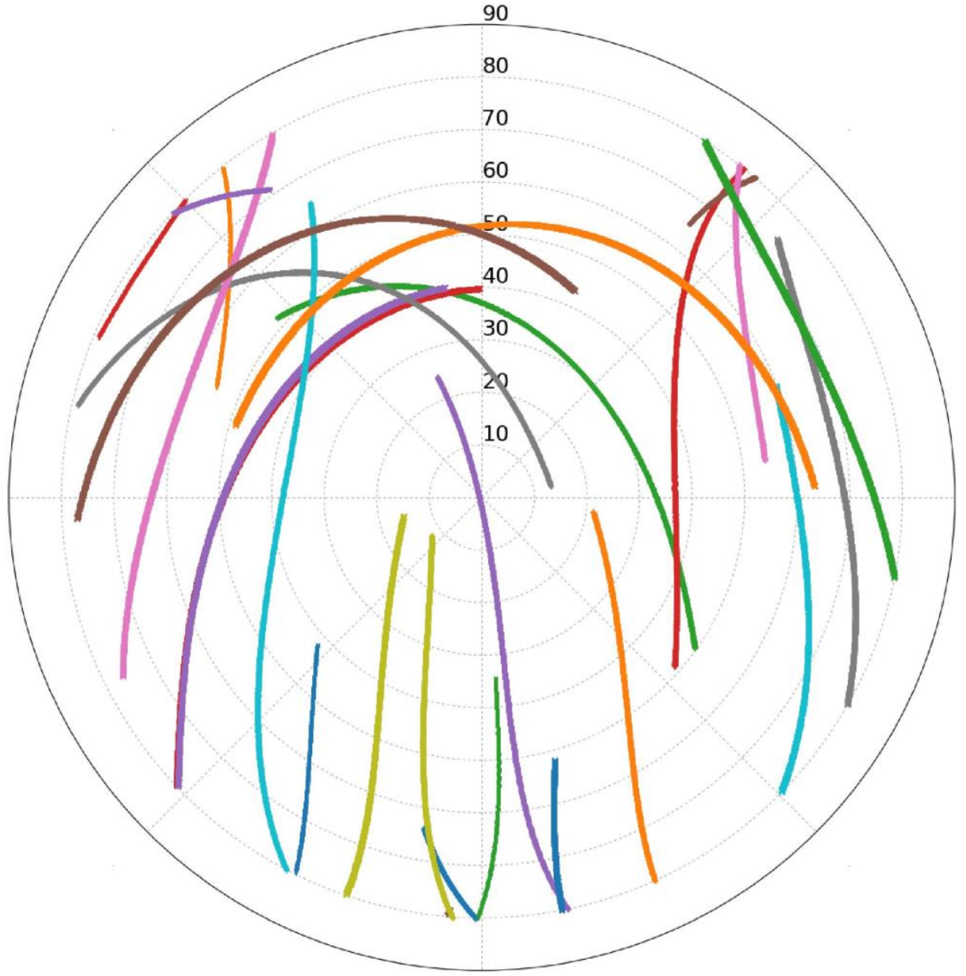
2653579.215 m (N)
326945.689 m (E)

Scale Factors
0.99996992 (point)
0.99992390 (combined)

*(Coordinates from RINEX header used as a priori position)

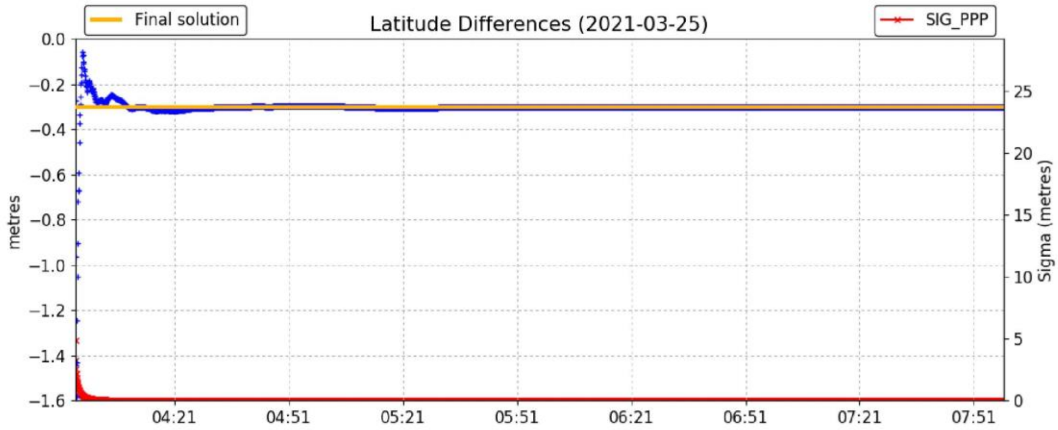
1

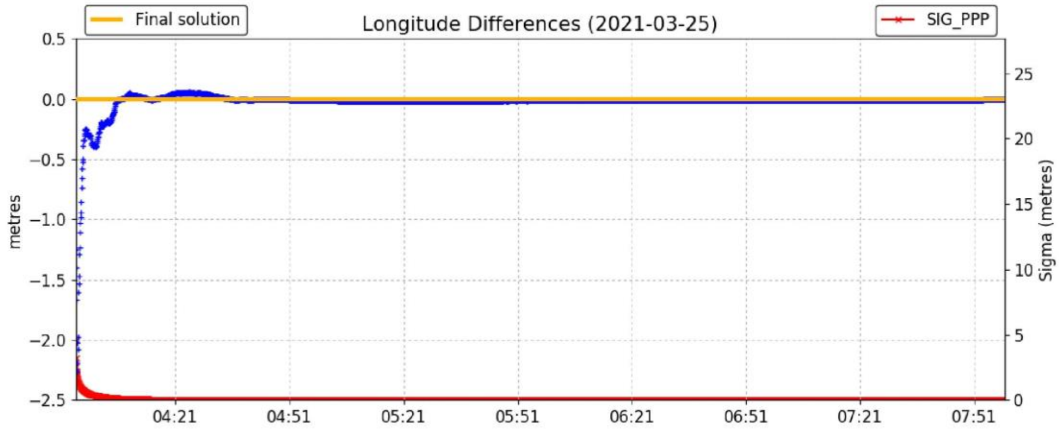
Satellite Sky Distribution

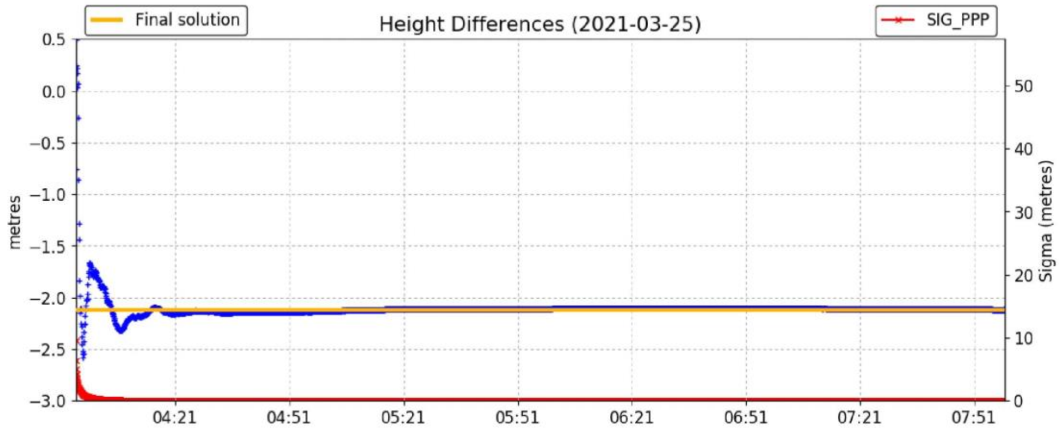


G01	G08	G17	G28	R03	R13
G03	G09	G19	G30	R04	R14
G04	G13	G21	R01	R08	R21
G06	G14	G27	R02	R12	R24
G07	G16				

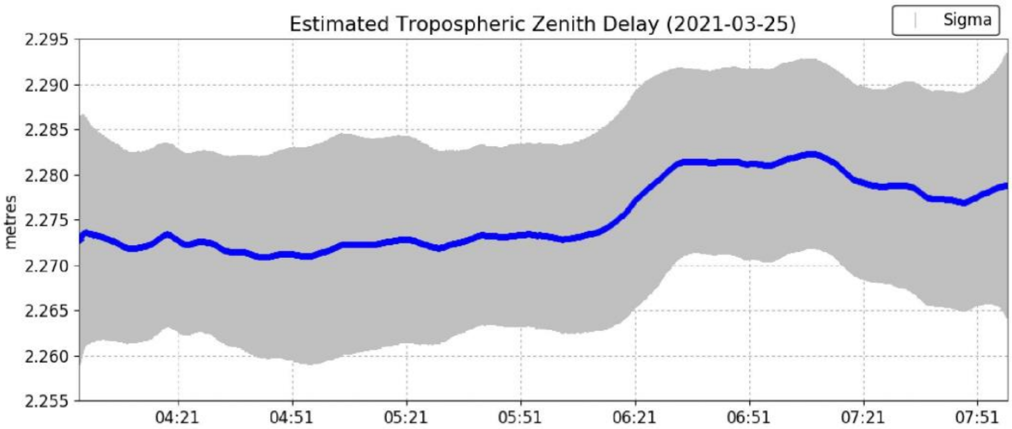
2

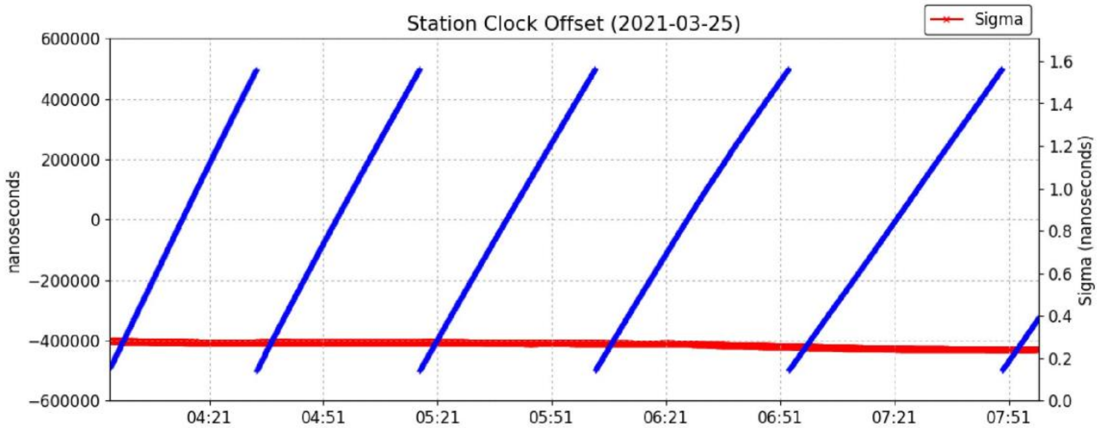

Final solution
Latitude Differences (2021-03-25)
SIG_PPP
metres
Sigma (metres)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
25
20
15
10
5
0
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51

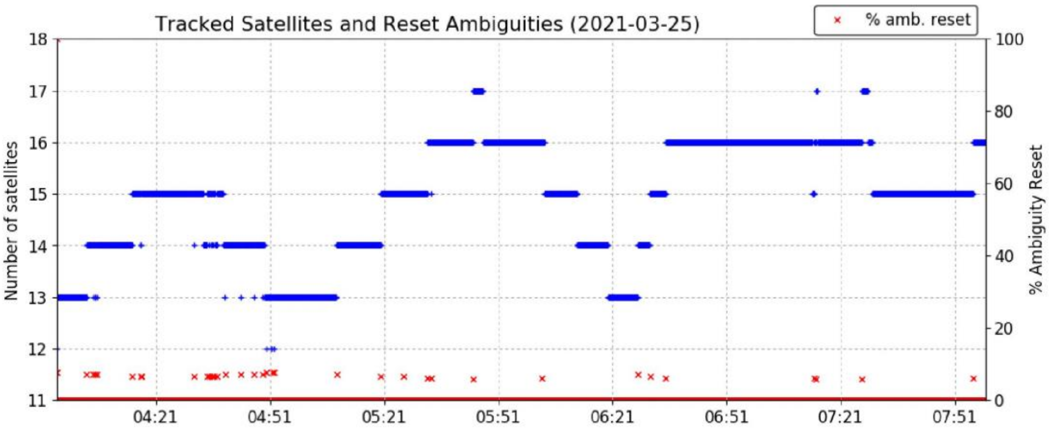

Final solution
Longitude Differences (2021-03-25)
SIG_PPP
metres
Sigma (metres)
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
25
20
15
10
5
0
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51


Final solution
Height Differences (2021-03-25)
SIG_PPP
metres
Sigma (metres)
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
50
40
30
20
10
0
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51

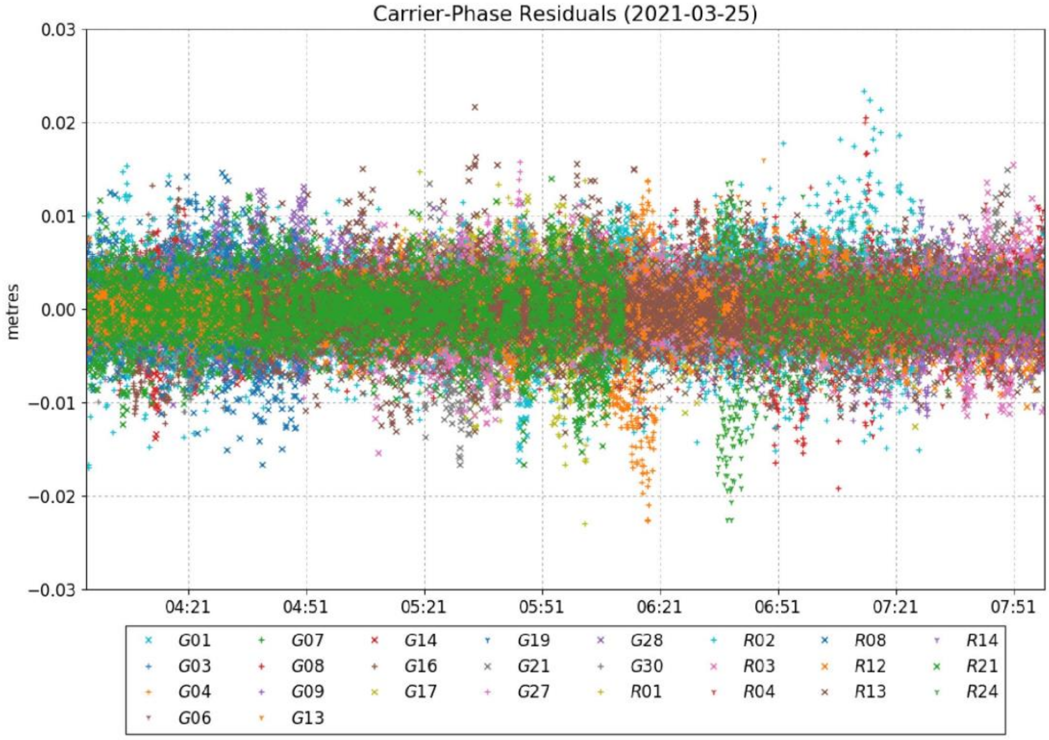
3

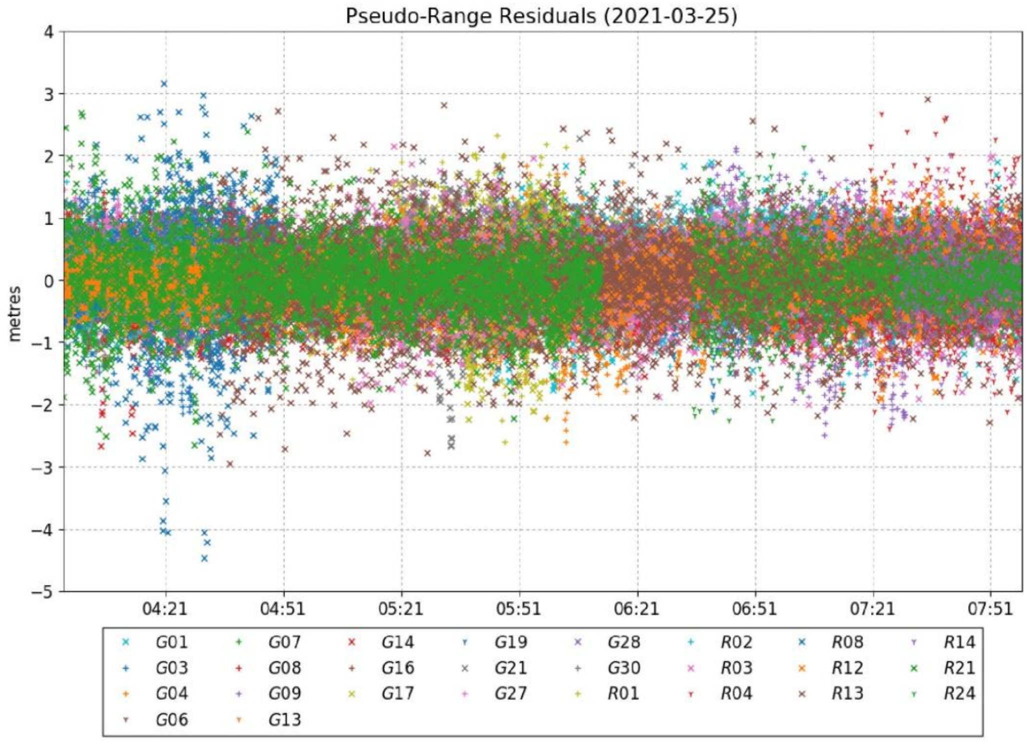

Estimated Tropospheric Zenith Delay (2021-03-25)
Sigma
metres
2.295
2.290
2.285
2.280
2.275
2.270
2.265
2.260
2.255
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51


Station Clock Offset (2021-03-25)
Sigma
nanoseconds
600000
400000
200000
0
−200000
−400000
−600000
Sigma (nanoseconds)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51


Tracked Satellites and Reset Ambiguities (2021-03-25)
% amb. reset
Number of satellites
18
17
16
15
14
13
12
11
% Ambiguity Reset
100
80
60
40
20
0
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51

4


Carrier-Phase Residuals (2021-03-25)
metres
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51
G01 G07 G14 G19 G28 R02 R08 R14
G03 G08 G16 G21 G30 R03 R12 R21
G04 G09 G17 G27 R01 R04 R13 R24
G06 G13


Pseudo-Range Residuals (2021-03-25)
metres
4
3
2
1
0
−1
−2
−3
−4
−5
04:21
04:51
05:21
05:51
06:21
06:51
07:21
07:51
G01 G07 G14 G19 G28 R02 R08 R14
G03 G08 G16 G21 G30 R03 R12 R21
G04 G09 G17 G27 R01 R04 R13 R24
G06 G13

5

8 SINGLE BEAM ECHOSOUNDER BAR CHECK RESULTS

GEOSERVICES MARITIME PVT. LTD.

QUALITY MANUAL AND PROCEDURE

Singlebeam Echosounder Barcheck Correction Table

Project No.	Project Title: **Bathymetric Survey**	BOAT: **AQUA MARINA**	Place: **HARNAV DAM**
Date: **26-Feb-21**	**09:30:00**		
Observed By: **Amit Singh**		Echosounder Model **SONARMITE**	Area Depth **10**

Draft		Sound Velocity	
		Average	Upto Depth
0.40		**1510**	**11**
Barcheck Frequency selected	Survey Frequency:	Manufacturer's Accuracy	
210	**210**	0.20 % of Depth	0.02 m

Observations while lowering			Observations while hoisting		
Bar Depth (m)	ES Reading (m)	ifference (m	Bar Depth (m)	ES Reading (m)	Difference (m)
3	2.98	0.02			
4	4.01	-0.01			
5	5.02	-0.02	8	8.03	-0.03
6	6.01	-0.01	7	7.02	-0.02
7	7.02	-0.02	6	6.02	-0.02
8	8.02	-0.02	5	5.01	-0.01
			4	4.02	-0.02
			3	2.99	0.01
	Average	-0.0100		Average	-0.0150
	Std. Dev	0.0155		Std. Deviation	0.0138
				Cumulative Average	-0.01
				Cumulative Std. Deviation	0.0012

The Echosounder Barcheck Values ar Negligible for Application

GMPL Party Chief

Approved By: Survey Manager

GEOSERVICES MARITIME PVT. LTD.

QUALITY MANUAL AND PROCEDURE

Singlebeam Echosounder Barcheck Correction Table

Project No.	Project Title:	BOAT:	Place:
	Bathymetric Survey	**AQUA MARINA**	**HARNAV DAM**
Date:			
27-Feb-21	**09:25:00**		
Observed By:		Echosounder Model	Area Depth
JOMON MJ		**SONARMITE**	**10**

Draft		Sound Velocity	
		Average	**Upto Depth**
0.40		**1510**	**11**
Barcheck Frequency selected	**Survey Frequency:**	Manufacturer's Accuracy	
210	**210**	0.20 % of Depth	0.02 m

Observations while lowering			**Observations while hoisting**		
Bar Depth (m)	ES Reading (m)	ifference (m	Bar Depth (m)	ES Reading (m)	Difference (m)
3	2.98	0.02			
4	4.01	-0.01			
5	5.02	-0.02	8	8.03	-0.03
6	6.01	-0.01	7	7.02	-0.02
7	7.02	-0.02	6	6.02	-0.02
8	8.02	-0.02	5	5.01	-0.01
			4	4.02	-0.02
			3	2.99	0.01
	Average	-0.0100		Average	-0.0150
	Std. Dev	0.0155		Std. Deviation	0.0138
				Cumulative Average	-0.01
				Cumulative Std. Deviation	0.0012

The Echosounder Barcheck Values ar‹ Negligible for Application

GMPL Party Chief

Approved By: Survey Manager

GEOSERVICES MARITIME PVT. LTD.

QUALITY MANUAL AND PROCEDURE

Singlebeam Echosounder Barcheck Correction Table

Project No.	Project Title:	BOAT:	Place:
	Bathymetric Survey	**AQUA MARINA**	**HARNAV DAM**
Date: **28-Feb-21**	**9:00**		
Observed By: **JOMON MJ**		Echosounder Model **SONARMITE**	Area Depth **10**

Draft	Sound Velocity Average	Sound Velocity Upto Depth
0.40	**1510**	**15**

Barcheck Frequency selected	Survey Frequency:	Manufacturer's Accuracy	
210	**210**	0.20 % of Depth	0.02 m

Observations while lowering			Observations while hoisting		
Bar Depth (m)	ES Reading (m)	ifference (m	Bar Depth (m)	ES Reading (m)	Difference (m)
3	2.98	0.02			
4	4.01	-0.01			
5	5	0	8	8.03	-0.03
6	6.01	-0.01	7	7.02	-0.02
7	7.02	-0.02	6	6.02	-0.02
8	8.02	-0.02	5	5	0
			4	4.02	-0.02
			3	2.99	0.01
	Average	-0.0067		Average	-0.0133
	Std. Dev	0.0151		Std. Deviation	0.0151
			Cumulative Average		-0.01
			Cumulative Std. Deviation		0.0000

The Echosounder Barcheck Values ar‹ Negligible for Application

GMPL Party Chief

Approved By: Survey Manager

9 PHOTOGRAPHS

The following Photographs showing the Survey activities and features available at site

Harnav dam details

Configuration of SBES Equipment

Water Level from RTK

END OF REPORT