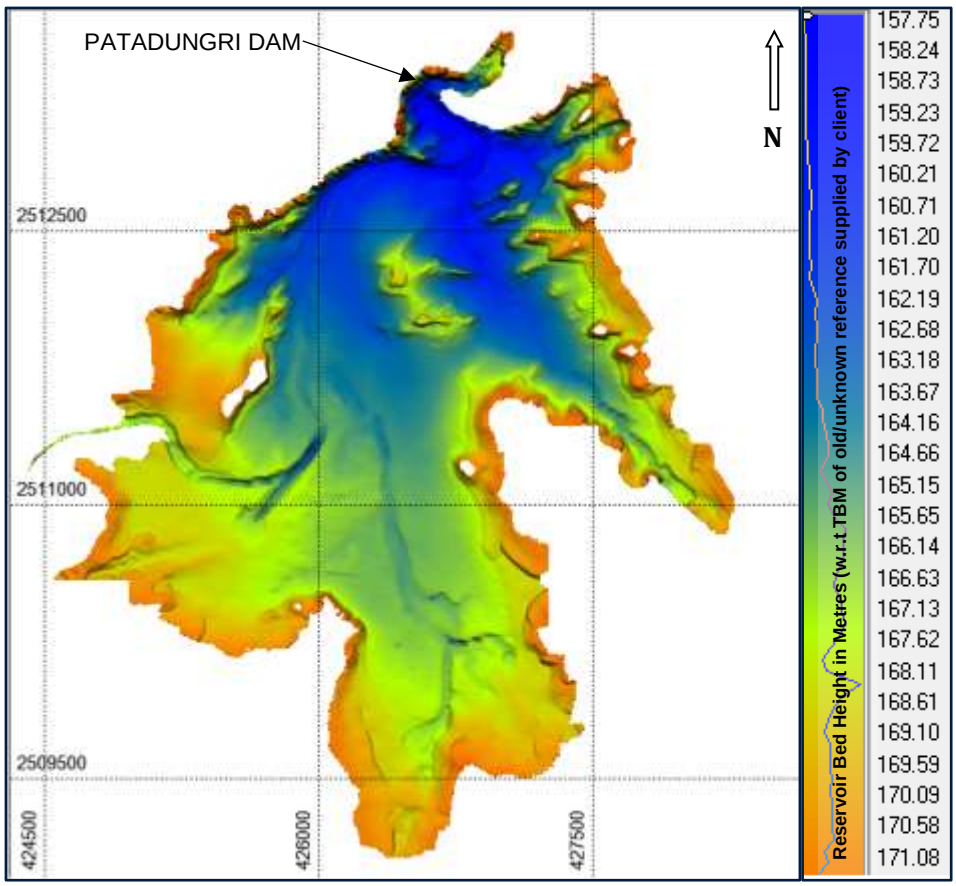

Providing Services for Conducting Bathymetric Survey of Reservoirs of Central Gujarat Under National Hydrology Project

Survey Results of Patadungri Reservoir Location | Central Gujarat

JHYD20-174630-Volume 2-Patadungri Reservoir/R1 [01] | 1 October 2021

Final Report

Narmada Water Resources, Water Supply and Kalpsar Department / Government of Gujarat

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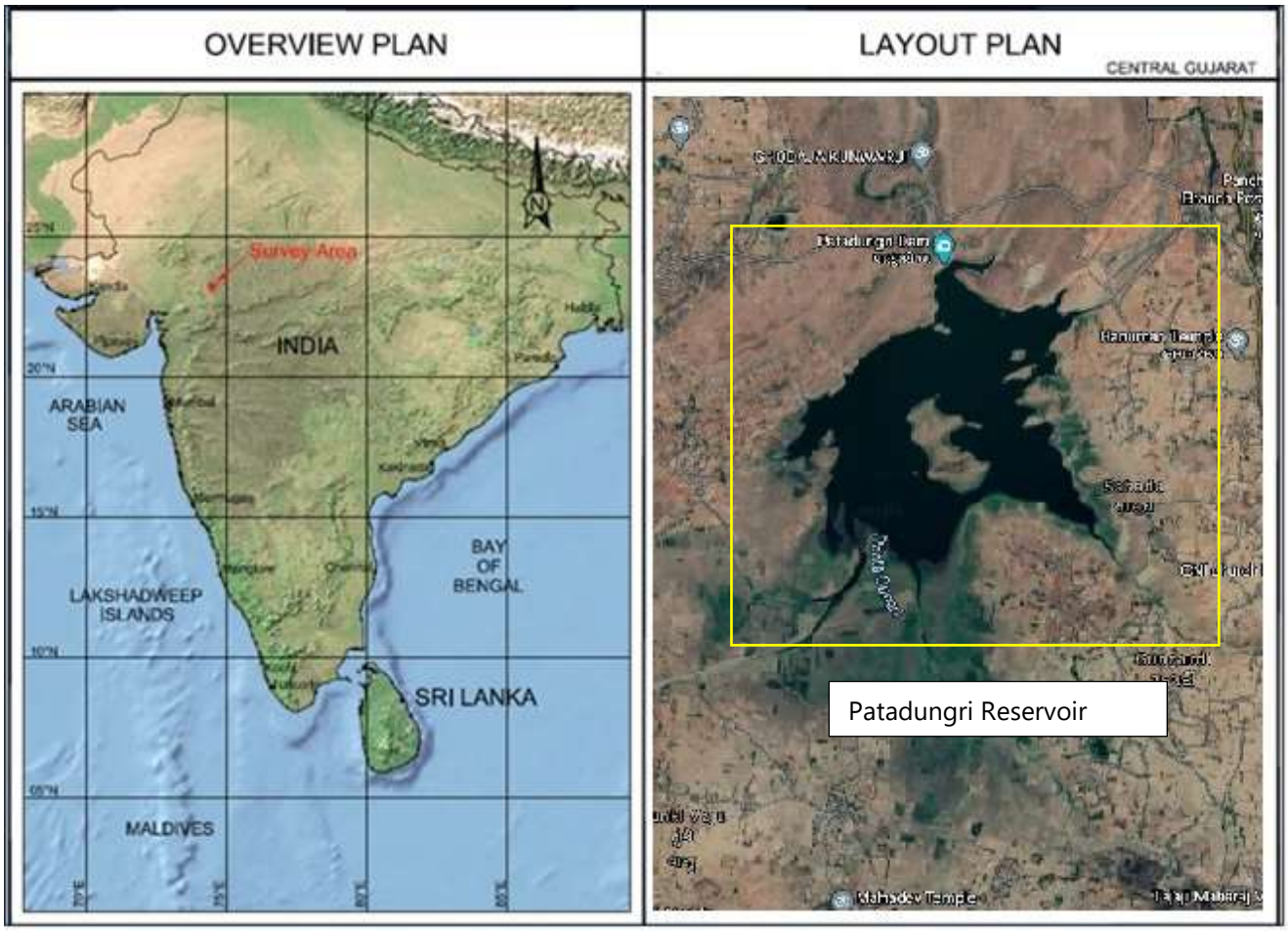
Rev	Date	Status	Prepared By	Checked By	Approved By
[01]	1 October 2021	Final Report	Alok A / Sukla C	G.N. Hariharan	Rahul Patkar

LOCATION MAP



EXECUTIVE SUMMARY

Survey Results - Patadungri Reservoir

Preamble:	The Gujarat State Government is implementing World Bank assisted national hydrology project. This project aims to improve the planning, development, and management of water resources, as well as flood forecasting and reservoir operations in real-time. Various activities, including Sediment survey, Water Quality monitoring have been planned under this project. Water Resources department have evolved a comprehensive plan for periodic assessment of reservoir storage capacity and sedimentation of eleven (11) reservoirs. In this regard, **Narmada Water Resources, Water Supply and Kalpsar Department/ Government of Gujarat** contracted **Fugro Survey (India) Pvt. Ltd. (FSINPVT)** to carry out the Bathymetry and Topography survey. Fugro's scope of work consist of Bathymetry and Topography survey at the eleven (11) reservoirs In order to complete the scope, the survey was carried out in two passes; • Pass 1: Bathymetry / Hydrographic Survey. • Pass 2: Topographical Survey
Data Acquisition:	**FSINPVT** mobilised their topographical and bathymetry survey team and equipment along with survey boat 'Polaris' which was deployed in the month of March 2021 and April 2021 in order to acquire survey data as per mutually agreed scope and relevant survey specifications.
Survey Location	Patadungri Reservoir, Patadungri village, Garbada Taluka, District – Dohad, Gujarat.
Survey Geodesy:	The survey was conducted in WGS 84 datum, Universal Transverse Mercator (UTM) Projection, Zone 43 N, CM 075°E.
Scope Compliance & Meets Client's objectives:	FSINPVT performed this survey methodically as per the scope of work defined in the contract and the results obtained have met the client's objectives in following areas: ▪ To assess the reservoir storage capacity; ▪ To assess the variations in the reservoir capacity; ▪ To estimate and study sedimentation behaviour in horizontal zones and vertical zones, namely dead storage, live storage and flood storage; ▪ To upgrade Elevation–Area-Capacity tables / curves of reservoir at regular intervals; ▪ To create historical database for further water resources usage planning.
Accuracy and Reliability	The accuracy of the data logged was ensured by calibrating each and every sensor deployed in the current survey. Statistical techniques were applied during the execution of the survey to ensure that the results of survey conform to the agreed levels of accuracy and precision.
Reservoir water level correction	All raw water depths were reduced to reservoir water levels. The water level heights or reservoir water levels w.r.t. client supplied unknown/old reference TBM were observed for the entire survey period and the same was used to calculate the reservoir bed heights.

Survey Findings – Patadungri Reservoir Location	
Reservoir Bed Heights	In general, lowest reservoir bed level was found at the upstream face of the dam and it becomes less deeper as we go further upstream from the dam face. Lowest reservoir bed level recorded during bathymetry survey was 157.8 m (517.7 ft) w.r.t. client supplied TBM (426 618 mE, 2 513 175 mN) and highest reservoir bed elevation mapped during topography survey was FSL 170.84 m (560.5 ft) w.r.t. client supplied TBM (427 500 mE, 2 513 152mN) within the survey area.
Capacity Survey (2020-2021)	Elevation Area Capacity table and curve of Patadungri reservoir was prepared based on bathymetry and topography survey data acquired at 25 m line spacing and 25 m x 25 m grid interval respectively. The processed xyz data was used to prepare DTM. Capacity and areas at various elevations from lowest bed level to FRL 170.84 m (560.5 ft) was calculated using GIS software.
Revised elevation area capacity details	In comparison with 1954 Original Project data, the present survey results indicate that the gross storage capacity has decreased. In comparison with 1982-83 survey results, further reduction in gross capacity was noticed. As per the revised elevation area capacity curve for the year 2020-2021, the storage capacity is found to be close to year 1982-83.
Loss in gross storage capacity	As per 2020-21 survey results, the loss in Gross storage capacity w.r.t. 1954 or volume of sediment deposited in the Patadungri reservoir is 8.029 M m^3 (283.541 M ft^3).
Trap efficiency & Sedimentation Index	Trap Efficiency and sedimentation Index calculated for Patadungri reservoir as per methodology give in IS 12182-1987 is 96% and 6.9 x 10^{10} s^2/m respectively
Sedimentation rate	The rate of siltation in Patadungri reservoir is 0.124 Mm^3/year
Average rate of siltation	The observed average rate of siltation in the Patadungri reservoir during the 67-year life span (1954 – 2021), works out to 4.813 Ha m/100 sq km/year (101.054 Acre-ft/100 mi^2/Year)
Annual % loss	The annual % loss in gross storage capacity for Patadungri reservoir during the 67-year life span is 0.292% and hence, the reservoir is classified as “Significant category” as per IS 12182 (1987).

CONTENTS

APPENDICES

TABLES

FIGURES

LIST OF ABBREVATIONS

BM	Benchmark
Ch	Channel
CM	Central Meridian
CVT	Calibration, Verification & Test
DF	Dual Frequency
DGNSS	Differential Global Navigation Satellite System
DPR	Daily Progress Report
FBF	Fugro Binary Format
FRL	Full Reservoir Level
FSINPVT	Fugro Survey (India) Private Limited
ft	Feet
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
Ha	Hectare
HSE	Health, Safety and Environment
km	kilometre
m	metre
M ft^3	Millions cubic feet
M m^3	Millions cubic meter
MDDL	Maximum Draw Down Level
m/s	meter per second
ms	milliseconds
MSL	Mean Sea Level
OEM	Original Equipment Manufacturer
QA/QC	Quality Assurance / Quality Control
QMS	Quality Management System
Rel	Release
Rev	Revision
RL	Reference Level
SBES	Single beam Echosounder
Sr	Senior
SoW	Scope of Work
UTM	Universal Transverse Mercator
WGS	World Geodetic System
w.r.t	With respect to

UNITS

UTM grid coordinates and all linear measurements are reported in metres [m].

Angular values are reported in degrees (°).

Time and dates are reported as “18:00 on 20 July 2021

1. Introduction

1.1 General

Reservoirs originated by the construction of dams, is essential for the sustainable health and welfare of civilizations since it supplies water for human consumption, irrigation and energy production. Furthermore, dam reservoirs are used for recreation, navigation and they provide safety in the downstream valleys against extreme flood events and droughts (Bengtsson et al., 2012). All reservoirs are subjected to sedimentation which, without adequate prevention and mitigation counter-measures, threatens their sustainability.

Reservoir sedimentation is the gradual accumulation of the incoming sediment load from a river. This accumulation is a serious problem in many parts of the world and has severe consequences for water management, flood control, and production of energy. Sedimentation affects the safety of dams and reduces energy production, storage, discharge capacity and flood attenuation capabilities. It increases loads on the dam and gates, damages mechanical equipment and creates a wide range of environmental impacts (Schleiss et al., 2016).

Reservoir sedimentation is a process of erosion, transportation, deposition and compaction of sediment carried into reservoirs formed and contained by dams. In unregulated, mature rivers with stable catchments, sediment processes are relatively balanced. Construction of a dam decreases flow velocities, initiating or accelerating sedimentation.

Most of the world's reservoirs are in the continuous sediment accumulation stage. Many were designed by estimating sedimentation rates in order to provide a pool with sufficient volume to achieve a specified design life. However, this design life is typically far less than what is actually achievable. Therefore, managing reservoirs to achieve a full sediment balance is essential in order to maximize their lives. As every year sediment gets deposited in dead storage and in live storage of the reservoir, it has long and short range impact on the storage capacity of reservoir (Schellenberg et al., 2017). Correct assessment of the reservoir storage capacity is essential for assessing useful life of the reservoir as well as optimum reservoir operation schedule.

The Gujarat State Government is implementing World Bank assisted national hydrology project. This project aims to improve the planning, development, and management of water resources, as well as flood forecasting and reservoir operations in real-time. Various activities, including Sediment survey, Water Quality monitoring have been planned under this project. Water Resources department have evolved a comprehensive plan for periodic assessment of reservoir storage capacity and sedimentation of eleven (11) reservoirs.

In this regard, **Narmada Water Resources, Water Supply and Kalpsar Department/ Government of Gujarat** contracted **Fugro Survey (India) Pvt. Ltd. (FSINPVT)** to carry out the Bathymetry and Topography survey. Fugro's scope of work consist of Bathymetry and Topography survey at the eleven (11) reservoirs, as specified by Client.

These survey services comprised of the provision of suitable personnel and equipment in order to obtain, interpret and report on the bathymetry and topography within the survey area. In order to complete the scope, the survey was carried out in two passes;

Pass 1: Bathymetry / Hydrographic Survey;

Pass 2: Topographical Survey.

The bathymetry survey work was performed from the shallow draft boat 'Polaris'.

The survey reports are submitted in separate volumes for each reservoir location. This report covers **Bathymetry / Hydrographic and Topographical survey results for Patadungri Reservoir location.**

1.2 Study Area

The present study area – Patadungri reservoir falls within Mahi basin. Mahi basin is sub-divided into two sub-basins namely Mahi upper sub basin and Mahi lower sub basin. Basin drainage and sub-basin boundary is given in Figure 1.1. Mahi upper sub basin (65.11% of total basin area) consists of 41 watersheds and Mahi lower sub basin (34.89% of total basin area) consists of 22 watersheds. The basin has maximum length and width of about 330 km and 250 km, respectively. The Mahi basin covers an area of 15,474 km^2 (40.36%) in Gujarat accounting to 41.73% of the total basin area. The Mahi River and its tributaries constitute an inter-state river system flowing through the states of Madhya Pradesh, Rajasthan and Gujarat. Mahi river is comprised of several tributaries on both the banks, viz. Som, Anas, Panam and others. The Anas River, a left bank tributary of Mahi River, rises from Jhabua district of Madhya Pradesh joining Mahi in Dungarpur district of Rajasthan.

The Patadungri reservoir/dam situated in Mahi upper sub-basin is built on Khan River, which flows into the Anas River, a left bank tributary of Mahi River. The Khan River basin is located in Dahod, Gujarat and Jhabua, MP. It has a highest elevation of around 1300 ft above MSL and flows into Anas at around 900 ft above MSL with the main flow of river about 40-42 kms in length. This is an important river for Dahod since the city is located inside this river basin and the main reservoir supplying water to the city is the Thakkar Bapa Reservoir, also known as Patadungri reservoir.

Within the river basin, intensive agriculture is found close to the check dams. As one extends further from the dam area, groundwater based irrigation system is also found within this zone. The data on land utilization and irrigation shows that, in Dahod district, cultivation and sowing land covers 3090 Ha, where area sown more than once covers 945 Ha. In the district, forest area covers 884 Ha (Nayak, 2014).

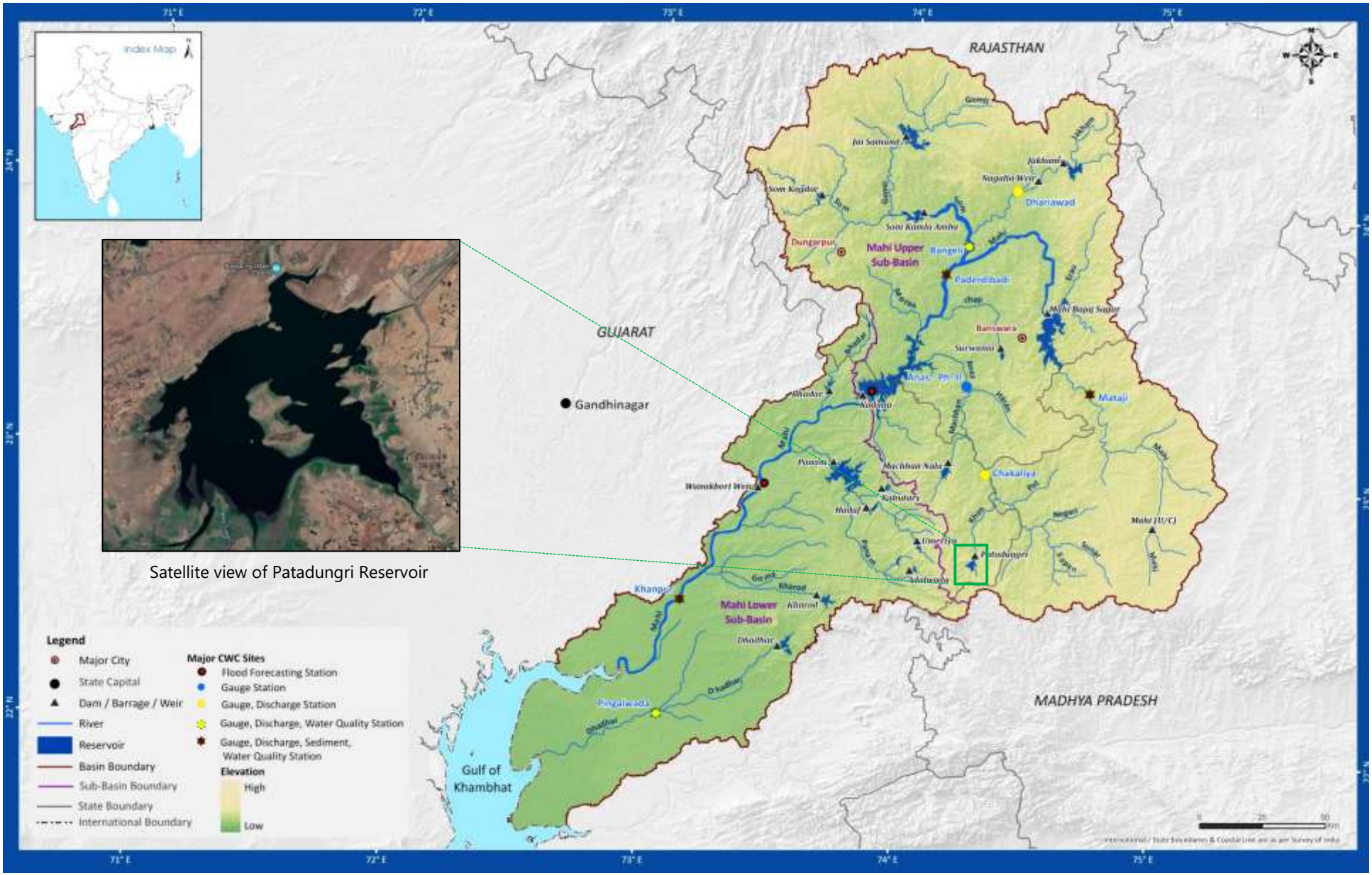


Figure 1.1: Mahi basin showing major tributaries – Drainage and sub-basin (Courtesy: India-WRIS, 2014)

1.3 Geology of Study Area

Dahod district is a manifestation of complex geological extension from Archaean to modern times, with a variety of rock types ranging from granitic to basalt, limestone to alluvium. In the southern part of the district, Archaean rock with Granite gneiss and biotite gneiss is the oldest formation. Godhra granite and gneisses from the post-Delhi intrusive were intruded into older Archaean. Deccan basalts, an extrusive rock formation, occur as intermittent exposure in the form of cappings over older rocks. The alluvium is the most recent formation; it can be found as pediments, sand dunes, valley fills, and flood plains along river courses in isolated patches. The Deccan volcanic, which is exposed in the central part of Dahod and Jhalod talukas, is made up of basalts and rhyolite (Nayak, 2014).

1.4 Soil Types

The soil type of Dahod district is broadly categorized depending on the source rock, i.e., Phyllite, Granite and Basalt. Intense weathering of basalts in this area resulted in formation of black cotton soils which have high fertility value. In this area, sandy loamy soil (from granite) and yellowish light soil (from phyllite) are also found at places of intense weathering (Nayak, 2014).

1.5 Patadungri Reservoir Characteristics

The Patadungri dam is an earthen (rolled filled zone type) dam constructed over the Khan River. Refer Appendix F for details of client supplied elevation area capacity curve for the year 1954 (Project data) and 1982-83 survey for the Patadungri reservoir. Salient features of the Patadungri reservoir are tabulated below:

Table 1.1: Patadungri Reservoir Salient Features (Courtesy: Narmada, Water Resource, Water Supply and Kalpsar Department)

Characteristics	Feature
Reservoir name	Patadungri Reservoir
Location	Patadungri village, Garbada Taluka, District – Dahod, Gujarat
Purpose	Irrigation and water supply
River	Khan
Location	
Main dam	Latitude: 22° 43′ 33″ N Longitude: 74° 17′ 05″ E
Waste weir	Latitude: 22° 43′ 22″ N Longitude: 74° 17′ 37″ E
Year of commencement of construction work	1953-1954
Year of completion	(i) 1957 - Head works (ii) 1961- 62 R.B. canal (iii) 1973- 74 All works

Characteristics	Feature	
Details of storage		
Lowest level of River bed at @ Dam site	493.00 feet (150.266 m)	
Sill level	525.00 feet (160.02 m)	
Full Supply Level (F.S.L.)	560.50 feet (170.84 m)	
High Flood Level (H.F.L.)	567.50 feet (172.974 m)	
Live storage (1954)	1400.00 Mft^3 (39.643 Mm^3)	
Dead storage (1954)	50.00 Mft^3 (1.416 Mm^3)	
Gross storage (1954)	1450.00 Mft^3 (41.059 Mm^3)	
Area at full reservoir level	10 km^2	
Details of waste weir	Ogee shaped waste weir: 448 feet (136.55 m)	
Nature of Catchment	Hilly and fan shaped	
Area of catchment	249 km^2	
Mean annual runoff in the catchment	55 Mm^3	
Mean annual rainfall	732.54 mm	
Details of dam		
Dam Type	Earthen (rolled filled zone type)	
Length at the top of the dam	198.73 m	
Maximum height above the lowest point of foundation	83.0′ (25.30 m)	
Top R. L. of dam	576.00′ (175.56 m)	
Rock type at dam site	Quartzite	
Details of Head Regulator		
Type and no. of Head Regulator	Well Type of 16′ (4.88 m) and 2 nos.	
Size of Tunnel	4′x7′ above 2′ Arch Type	
Length of Tunnel	95′	
Size of Gate	4′ x 7″	
Canals		
Discharge through Head Regulator	180 cusecs	
	Left Bank	Right Bank
Design discharge	40.00 cusecs	180.00 cusecs
Length	14.50 km	41.00 km
Details of command/ irrigation		
G. C. A.	15408 acres (6235 ha.)	
C. C. A.	12534 acres (5072 ha.)	
I. C. A.	Left Bank	Right Bank
	3286 acres (1330 ha.)	7862 acres (3183 ha.)
Total	11148 acres (4513 ha.)	

1.6 Project Objectives

Primarily the main objective of the survey was to:

- Assess the reservoir storage capacity;
- Assess the variations in the reservoir storage capacity;
- Create historical database for further water resources usage planning.

However, the main objective of the bathymetry survey was to:

- Estimate and study the sedimentation behaviour of reservoirs in different zones including horizontal zones throughout the reservoirs as well as vertical zones namely:
    a) Dead storage
    b) Live storage
    c) Flood storage
- Upgrade Elevation-Area-Capacity tables / curves of reservoirs at regular intervals.

Table 1.2 provides bathymetry and topography survey area details for Patadungri reservoir.

Table 1.2: Patadungri Reservoir details for Bathymetry and Topography Survey

Name of Dam / Reservoir	Actual Area (km^2) surveyed	
	Bathymetry Survey	Topography Survey
Patadungri	4.09	2.8

1.7 Scope of Work

To achieve the above objective, Fugro carried out survey of Patadungri reservoir in two (02) passes. The scope of work undertaken for Patadungri reservoir is as follows:

1.7.1 Pass 1: Bathymetry / Hydrographic Survey

The scope of work for bathymetry survey conforms bathymetry survey for total area of approximately 4.09 km^2.

The following scope of work was undertaken in-order to achieve client objectives:

- Bathymetry / Hydrographic survey work was conducted using echosounder for assessment of reservoir capacity and sedimentation at Patadungri reservoir of Gujarat.
- Survey lines were run at 25 m segment line spacing and along the survey line continuous data of 25 m x 25 m grid point were captured so that each and every point is included. Additional survey lines were executed as and when required.
- DGNSS positioning system, Dual frequency singlebeam echosounder system along with associated Navigational system were deployed on all the survey lines.

1.7.2 Pass 2: Topographical Survey

Topographical survey was carried out using GNNS RTK system. The total area covered in Topographical survey is 2.8 km^2. Following scope of work was undertaken in order to achieve client objectives:

- Topographical survey was conducted to facilitate hydrographic survey so as to fill up the gaps between MWL area and reservoir submergence area till current water level for assessment of reservoir capacity and sedimentation at the reservoir locations.
- Topographical survey was carried out from FRL (FSL) to present water level of reservoir, with sufficient overlap with hydrographic survey for preparing overall contour map of reservoir.
- The area not covered through hydrographic survey up to maximum water level (MWL), was surveyed by taking levels at 25 m interval along range lines laid at 25 m interval (25 m x 25 m grid).

1.8 Survey Execution

The survey boat 'Polaris' was mobilized at Patadungri reservoir location to carry out the survey. Survey operations were executed as per the mutually agreed survey execution schedule.

1.9 Reference Documents

Table 1.3: Reference Documentation

Sl/No.	Document Name	Document identity
1	FSINPVT Quote / Contract	NOA No. WRIDn/SK/NOA/1588/2020 Dated 09 November 2020
2	FSINPVT Survey Procedure	JHYD20-174630/SP/P0/Rev.0 dated 01 December 2020

1.10 Deliverables

Final report and Charts / Drawings to be delivered as per the contract, as listed in Appendix G to this Report, have been duly submitted. Details of the Charts accompanying this report are also placed at Appendix G.

2. Survey Specifications and Resources

The bathymetry / hydrographic survey and topography survey conformed to the following mutually agreed scope of work and were conducted as per the methodology described in the standard work instruction by FSINPVT.

2.1 Survey Geodesy

The survey was conducted in WGS84 Datum and grid coordinates in terms of Universal Transverse Mercator (UTM) projection (Zone 43 N, CM 075° E) as per client's instruction. The details of the Geodetic parameters are as follows:

Table 2.1: Geodetic Datum, Projection Parameters

Global Positioning System Geodetic Parameters	
Datum:	World Geodetic System 1984
Spheroid:	World Geodetic System 1984
Semi major axis:	a = 6 378 137.000 m
Inverse Flattening:	1/f = 298.257 223 563
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
Scale factor on Central Meridian:	0.9996
Units:	Metre
Notes: • The Client has specified the above Datum and Transformation parameters to be used for this survey. • Fugro's Starfix software suite always uses WGS84 as the primary datum for all geodetic calculations.	

2.2 Horizontal Control

Spatial Dual was used for positioning the survey vessel during this survey. Spatial Dual is a rugged GPS aided inertial navigation system that provides accurate position, velocity, acceleration and orientation under the most demanding conditions. It combines temperature calibrated accelerometers, gyroscopes, magnetometers and a pressure sensor with a dual antenna RTK GNSS receiver. They are coupled in a sophisticated fusion algorithm to deliver accurate and reliable navigation and orientation.

The computer running Starfix NG was used for navigation, data logging and online quality control of the survey data.

2.3 Vertical Control / Water Level Corrections

All vertical levels were reduced to respective water level references. The water level heights or reservoir water levels w.r.t. client supplied TBM were observed for the entire survey period and the same was used to calculate the reservoir bed height. Observed reservoir water level heights is tabulated below:

Table 2.2: Observed Reservoir Water Level heights at Patadungri

Date	Observed Reservoir Water Level w.r.t. client supplied TBM at Patadungri Reservior	
	Metres [m]	Feets [ft]
06-03-2021	168.57	553.05
07-03-2021	168.57	553.05
08-03-2021	168.55	552.99
09-03-2021	168.54	552.95
10-03-2021	168.54	552.95
11-03-2021	168.47	552.72
12-03-2021	168.45	552.67
13-03-2021	168.45	552.66
14-03-2021	168.45	552.66
15-03-2021	168.45	552.66
16-03-2021	168.45	552.66

2.4 Accuracy and Precision of Results

The accuracy of the data logged was ensured by calibrating each and every survey sensor deployed for the current survey, for eliminating systematic errors or bias. Internationally accepted survey work practices were adopted for carrying out such calibrations, sensor alignments and field verifications.

The quality of the data logged was monitored on-line using Fugro's on-line QC tools and ensured it met the agreed accuracy and precision levels. At the data processing, charting and reporting stages, the results of survey were further analysed and checked to ensure that they conformed to the agreed levels of accuracy and precision. The precision (or the repeatability) of the results of survey were controlled by adopting 'Statistical' techniques.

2.5 Survey Personnel Deployed

Following FSINPVT staffs were associated to bathymetry survey for this project.

Table 2.3: List of Survey Personnel – Bathymetry Survey 'Polaris'

Bathymetry Survey Personnel	
Personnel Name	**Function**
Arpit Bose	Party Chief / Surveyor
Mathiyazhagan V.	Engineer
Sunil Singh	Polaris Operator

Following FSINPVT staffs were associated to topography survey for this project.

Table 2.4: List of Survey Personnel – Topography Survey

Topography Survey Personnel	
Personnel Name	**Function**
Rambabu Sah + Survey Assistants	Topography Survey Team

Following onshore FSINPVT staffs were associated to this project.

Table 2.5: List of Personnel – Onshore Project Management and Data QC

Onshore Project Management and Data QC	
Personnel Name	**Function**
Rahul Patkar	Service Line Manager
Vikas Walanj/Anantha Krishnan	Project Manager
R.B. Jayaraman	Client Deliverable Manager
Avijit Nag	Survey Manager
G.N. Hariharan	Chief Geophysicist
Avinash Vasudevan	Reporting Manager
Prashant Mishra	Reporting Project Supervisor
K. Srinivas	Data Centre Manager

2.6 Equipment Deployed

Following equipment and systems were deployed for the survey work. The equipment setup and configuration diagram on the survey boat Polaris is placed at Appendix B to this document.

Table 2.6: Survey Equipment / Systems Deployed for Bathymetry Survey in Polaris

Equipment / System	Description / Make / Model/Resolution /Accuracies
Software / Navigation	Starfix.NG PC based data acquisition and survey vessel navigation package.
Positioning	Trimble BX-992 & Spatial Dual Receivers
Heading Sensor	Spatial Dual
Motion Sensor	Spatial Dual

Equipment / System	Description / Make / Model/Resolution /Accuracies
Sound Velocity	Odom DigiBar Pro
Single beam Echosounder	Echotrac E20 Dual Frequency Single Beam Echosounder

Table 2.7: Survey Equipment / Systems Deployed for Topographical Survey

Equipment / System	Description / Make / Model/Resolution /Accuracies
Land Survey	GNSS RTK System Lynx H6 along with accessories and consumables.

2.7 Survey Vessel

Shallow draft boat 'Polaris' was used to carry out the bathymetry / hydrographic survey.

Figure 2.1: Survey boat Polaris

2.8 Survey Database Used

Details of all existing engineering structures within the survey area, as supplied by the Client and interface boundaries drawn between land and water body, shallow patches taken from Google Earth images, were used as a background file in the navigation system during the entire tenure of survey.

- Client supplied TBM height – 170.050 m/ 557.90 ft w.r.t. unknown/old reference.
- FSL – 170.84 m (560.5 ft)
- Water line – 168.47 m (552.7 ft) approx.

3. Survey Data Acquisition

3.1 Survey planning, Preparation & Transportation to Site

The bathymetry survey equipment and personnel for survey boat 'Polaris' arrived at Patadungri reservoir location on 03 March 2021 and equipment was mobilised on-board the survey boat 'Polaris' on 04 - 05 March 2021.

After field testing / verification / calibration of all survey equipment, bathymetry survey was commenced and completed on 17 March 2021. Refer Appendix A to this document for diary of events.

Topography survey equipment and personnel arrived at Patadungri reservoir location on 07 April 2021. The topography survey was commenced on 08 April 2021 and completed on 14 April 2021.

3.2 Equipment Setup Configuration and Calibration

All survey equipment was installed and configured on-board the survey boat as per the 'Equipment Layout Diagram' placed at Appendix C to this document.

The location of the various survey sensors on the survey boat is given in the 'Vessel Offset Diagram' placed at Appendix B to this document.

3.3 Field Calibration and Verifications

All equipment used for the survey work were calibrated and bench tested prior to their mobilisation for this task. In addition, after installation on the survey vessels, extensive calibration, verification and tests were carried out in the field before deploying them for actual data acquisition. Standard survey methods were used for carrying out these calibrations / verifications and data acquisition, as described in the following paragraphs.

Refer to Appendix D of this document for the 'Results of the Calibrations / Verifications of Survey Sensors'.

3.3.1 Heading Sensor Alignment

Vessel heading was obtained onboard 'Polaris' from Spatial Dual. Spatial dual features dual antenna moving baseline RTK. This enables it to provide extremely accurate heading both at rest and at movement. It's a great option for situations where magnetic heading isn't possible due to interference or where extra precision is required. The system was tested at FSINPVT workshop prior to mobilization for the survey. The performance of the system was found to be satisfactory during the period of survey.

3.3.2 Navigation System

The Positioning System on board 'Polaris' was Spatial Dual. Position observations were done at Patadungri reservoir benchmark location (Patadungri TBM), using Trimble BX-992 and Spatial Dual receiver and was compared. Refer Appendix E for Benchmark description and Appendix D for details on position system verification results. The performance of the system was found to be satisfactory. Summary of the results of the position system verification is tabulated below:

Table 3.1: Results of Positioning System Verification

Sensor	Serial No.	Easting (mE)	Northing (mN)	Latitude	Longitude	Ellipsoidal Height (m)
Positioning System Verification Results With BX-992 and Spatial Dual Receiver (Polaris)						
Trimble BX-992	025-00009601	427673.600	2513098.021	22°43'25.070"N	74°17'44.475"E	274.839
Spatial Dual	025-272968	427673.369	2513097.916	22°43'25.067"N	74°17'44.467"E	274.828
Difference		**0.231**	**0.105**	**--**	**--**	**0.011**

3.3.3 Sound Velocity Measurements

Sound Velocity in the water column was measured in the survey area at regular intervals using sound velocity probe. Sound velocity profiles (cast) thus generated were used during post processing of SBES data.

3.3.4 Heave Compensator

Spatial dual is a high precision source for heave information. The system was tested at FSINPVT workshop prior to mobilization for the survey. The performance of the system was found to be satisfactory during the period of survey.

3.3.5 Single Beam Echosounder

Echotrac E20 dual frequency single beam echosounder was used for measuring water depths within the survey corridor. The echo sounder system was bench tested at FSINPVT workshop prior to mobilization for the survey. The echo sounder transducer was vertically side mounted on the survey boat and its draft below the waterline was measured and recorded. Heave compensator was connected to the echo sounder receiver. The echo sounder system was interfaced with the Starfix NG navigation and survey system for logging the depth vs position data. Sound velocity within water column was measured on a regular basis using sound velocity profiler and average sound velocity was entered in the top side unit of the echo sounder.

Table 3.2: Summary of Single Beam Echosounder Calibration Results by 'Bar Check' Method

Date	SBES Sensor Type	Average (m)	Standard Deviation
Summary of SBES Calibration Results on-board 'Polaris'			
06 March 2021	Echotrac E20 SBES	0.00	0.0027

3.4 Data Acquisition and Online Quality Control

On successful completion of mobilization and Calibration, Verification & Testing of all equipment as per the standard work practices, the survey data acquisition commenced as per the project plan to achieve the objectives of survey.

Navigation System, Heading and Bathymetry

The navigation data and vessel heading from the spatial dual, was logged continuously and monitored using the Starfix NG navigation suite. The survey data was logged in Fugro Binary Format (.FBF).

Event Markings

The on-line computer system was interfaced for closure to the analogue traces on the survey vessel. Event marks corresponding to position fixes were generated automatically from the on-line Navigation Computer interface at regular intervals of 25 m across the ground.

Survey Run-Line Logs

Survey lines were planned as per scope of work and digital pre-plots for the area was prepared prior to commencement of survey. These lines were run on the navigational computer while doing the survey and this enabled the Navigator to guide the boat along the planned survey line all the time. A survey line log was maintained which consists of the particulars about the surveyed line, Date, Time, Session Number, Event Number, KP, Sensors Deployed and all the significant events occurred during the survey.

3.4.1 On-line QC of Data Logged

FSINPVT follows standard procedures and has standard formats for documenting the Quality Control of acquired data for each sensor deployed during the survey. Experienced operators were constantly monitoring the real time data quality as the survey progressed. A log of profiles was maintained, and quality of data was noted. Re-shoots of survey lines were carried out as and when required.

All computers connected to the Navigation network were synchronized with the GPS (high precision) 1PPS time signal by means of the Starfix Timing Module, allowing all data to be time stamped.

The quality of data being recorded was constantly monitored in real time and fine-tuned to obtain the best quality. The data / record obtained from each survey sensor such as Navigation, Heading, SBES and Spatial dual were quality checked and an extract of the same were made available for verification and confirmation to proceed further.

3.5 Topography Survey

3.5.1 RTK Verification

The RTK system verification was carried out by 'Static Observations' for 30 minutes at client supplied Patadungri Dam Benchmark (Patadungri TBM) and Temporary Benchmark location (TBM 03).

3.5.2 RTK Position Comparison

The RTK observed position at client supplied benchmark (Patadungri-TBM) and Temporary Benchmark location (TBM-03) was compared with Trimble BX-992 Receiver position. Results of the comparison is tabulated below:

Table 3.3: Results of RTK Position Comparison

Sensor	Model No.	Easting (mE)	Northing (mN)
Patadungri-TBM (WGS 84, UTM Projection, CM 075°E, Zone 43N)			
Trimble BX-992	025-00009601	427673.600	2513098.021
RTK Rover 1	Lynx-H6	427673.581	2513097.979
Difference		**0.019**	**0.042**
Patadungri-TBM (WGS 84, UTM Projection, CM 075°E, Zone 43N)			
Trimble BX-992	025-00009601	427673.600	2513098.021
RTK Rover 2	Lynx-H6	427673.589	2513098.003
Difference		**0.011**	**0.018**

Refer Appendix D for RTK comparison details.

3.5.3 Topographical Survey Methodology

The area not covered under hydrographic survey i.e., between the existing water level at the time of survey up to Full Supply Level (FSL)-170.8 m (560.5 ft) has been carried out by topography survey method.

The topography survey was carried out using GNSS RTK Lynx-H6 system. The RTK system consist of two units i.e., Base receiver and Rover receiver. Corrected GPS signals are transmitted in real time from a base receiver at a known location to one or more rover receivers. Following steps were carried out while commencing and executing the topography survey operations:

- Components of Base and Rover receivers were setup at benchmark locations.
- Tripod was setup at base station i.e., at the temporary benchmark location (TBM-03 established by Fugro by levelling method) and thereafter the tripod was levelled and the RTK base station was configured.
- The rover receiver along with RTK pole was installed at Patadungri-TBM location. Static observation was carried out subsequently as part of verification.
- The Base receiver is installed at TBM-03 and configured the system with known coordinates and elevation (levelling carried out by Fugro). The rover receiver position and elevation are verified by setting up the system at Patadungri-TBM.
- Thereafter survey commenced by placing the rover receiver at 25 m grid interval and logging the position (easting, northing) and the elevation in relation to the base.
- Whenever the radio RTK coverage between rover receiver and base receiver is reduced, new check points were created and the base receiver was shifted to this newly created check point.
- Above procedure was followed and survey completed from the existing water line till achieving the HFL mark.

Figure 3.1: Client Supplied Benchmark (Patadungri-TBM)

Figure 3.2: Temporary Benchmark (TBM 03)

Figure 3.3: Photograph showing elevation measurement using RTK rover at water line

Figure 3.4: Photograph showing steep relief of ground noticed close to waterline

3.6 Survey Coverage and Scope Completion

FSINPVT carried out the bathymetry and topography survey operation methodically to meet the client's objectives from this survey.

- The survey work was carried out on par with the mutually agreed scope and objectives mentioned in the Section 1.6 of this document.
- Survey scope from existing water level up to the Full Supply Level (FSL)-170.840 m / 560.50 ft, was achieved by undertaking topography survey.
- All the bathymetric survey lines were run at appropriate spacing i.e., 25 m, so as to obtain data of 25 m x 25 m grid points.

4. Data Processing and Interpretation

4.1 Navigation and Positioning

- The survey data was logged in Fugro Binary format (FBF), and processed using the Starfix.Proc software. Heading, motion and position data were processed and checked to ensure good data quality. The position data for the various survey sensors were processed and plotted to allow commencement of the interpretation of the bathymetry data.
- The measured offsets for all survey sensors were entered into the navigation system and processed using Starfix.Proc to enable track charts to be plotted and 'corrected' navigation files to be integrated with other sensor data at a later stage. These included:
    - GPS position absolute of the primary & secondary positioning systems.
    - Common Reference Point

4.2 Bathymetry Data Processing

- SBES bathymetry data was reduced to Mean Sea Level (MSL), applying observed Reservoir Water Level / Height heights recorded at Dam. (Refer Figure 4.1)
- The data was filtered, cleaned, and combined to create geographically positioned bathymetric data set that has been corrected for MSL and sound speed.
- Starfix.Workbench & Mproc was used to quality check the data.

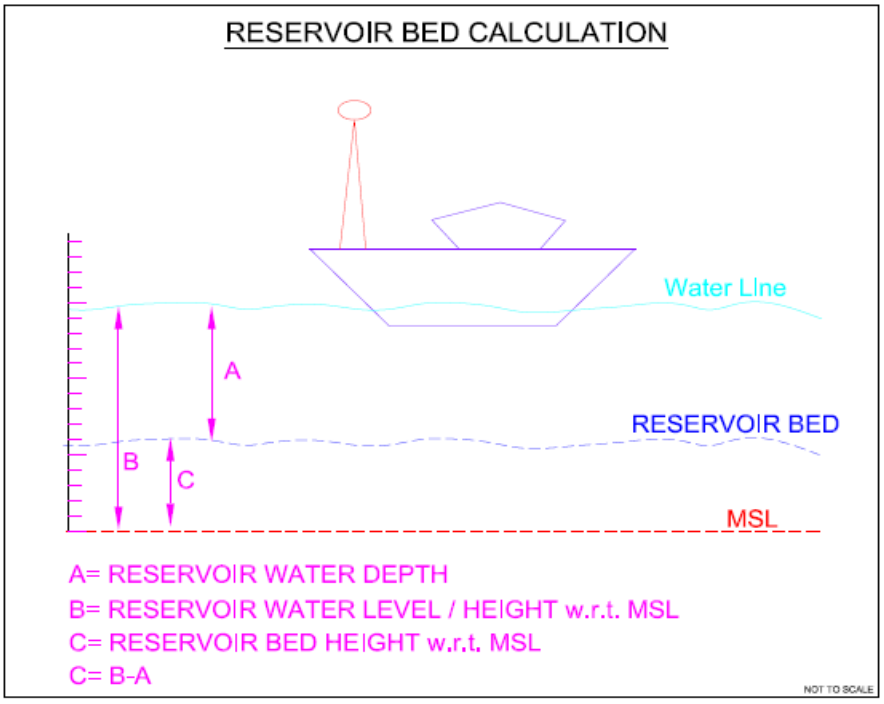


Figure 4.1: Reservoir Bed Height Calculation w.r.t. MSL

4.3 Creating Digital Terrain Model (DTM)

The bathymetric data and topographic data were then combined to create a vector point shapefile in GIS software. The boundary of the reservoir was then digitized around the point shapefile. Two types of boundaries were constructed. First boundary is outside the reservoir and second type of boundary consisted of the boundary around islands in the reservoir. This point shapefile was then utilized for creation of DTM. The DTM for the reservoir can be created by use of various algorithms such as Kriging, Radial Basis function, Inverse Distance Weighting (IDW) method and local polynomial function. Among these various methods, IDW can give the best interpolation accuracy for reservoirs (Shiferaw and Abebe, 2020). IDW method is a weighted average interpolation method. For every grid node, the resulting value Z will be calculated using the formula as given in (1).

$$Z = \frac{\sum_{i=1}^{n} \frac{Z_i}{r_i^p}}{\sum_{i=1}^{n} \frac{1}{r_i^p}} \quad (1)$$

Where:

- Z_i is the known value at point i,
- r_i is the distance from grid node to point i,
- p is the weighting power,
- n is the number of points in Search Ellipse.

Therefore, in this study IDW method has been used for the interpolation for the creation of DTM. The DTM thus created was saved in Tiff format. The created DTM was smoothed by use of various filtering operations. Thereafter, the DTM was clipped through extract by mask operations using the mask of boundary shapefiles created before. The final DTM thus obtained after clipping the DTM was then used for further analysis.

Contour maps at 1 m interval was also prepared using the DTM in Starfix.Workbench software.

4.4 Development of Area Capacity Curves

Area Capacity curves are useful tools for operational and planning purposes such as water management and sediment monitoring. By comparing the area capacity curves at different times, the rate of sedimentation in the reservoirs can be determined. These curves show the capacity and surface area of the reservoir at an indicated elevation above the reference elevation level. The elevation area capacity curves are prepared using the DTM for the reservoir site. For, this study the reference elevation level used for the preparation of Area capacity curve is 157.8 m which is the lowest bottom level for the reservoir and the maximum level considered is 170.84 m which is Full Supply Level (FSL) of the reservoir. The incremental value for elevation used for developing these curves is kept at 0.1 m. The surface area at the successive intervals was obtained in GIS software by intersecting the DTM with horizontal planes at an interval of 0.1 m starting from the

zero bed elevation till the FSL. The incremental volume (ΔV_i) between two contours was then calculated and integrated from bottom to specified elevation to obtain the required capacity at specified elevation. The method and formula used for volume calculation is the cone formula given by the equation 2.

$$\Delta V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right) \quad (2)$$

Where, ΔV is the incremental volume between two successive elevations; h is the incremental height between two successive elevations; A1 and A2 are the areas of two successive elevations.

4.5 Sedimentation in Different Zones of Reservoir

The sediment entering into the reservoir carried by the flowing river from the upstream catchments get deposited in the reservoir with the passage of time and reduces the live as well as dead storage capacity of the reservoir. This causes the bed level near the dam to rise. Live storage is from the level MDDL to FRL. Dead storage is from Bed Level to MDDL. Gross storage is from Bed Level to FRL. The sedimentation in different zones of reservoir is shown in Figure 4.2

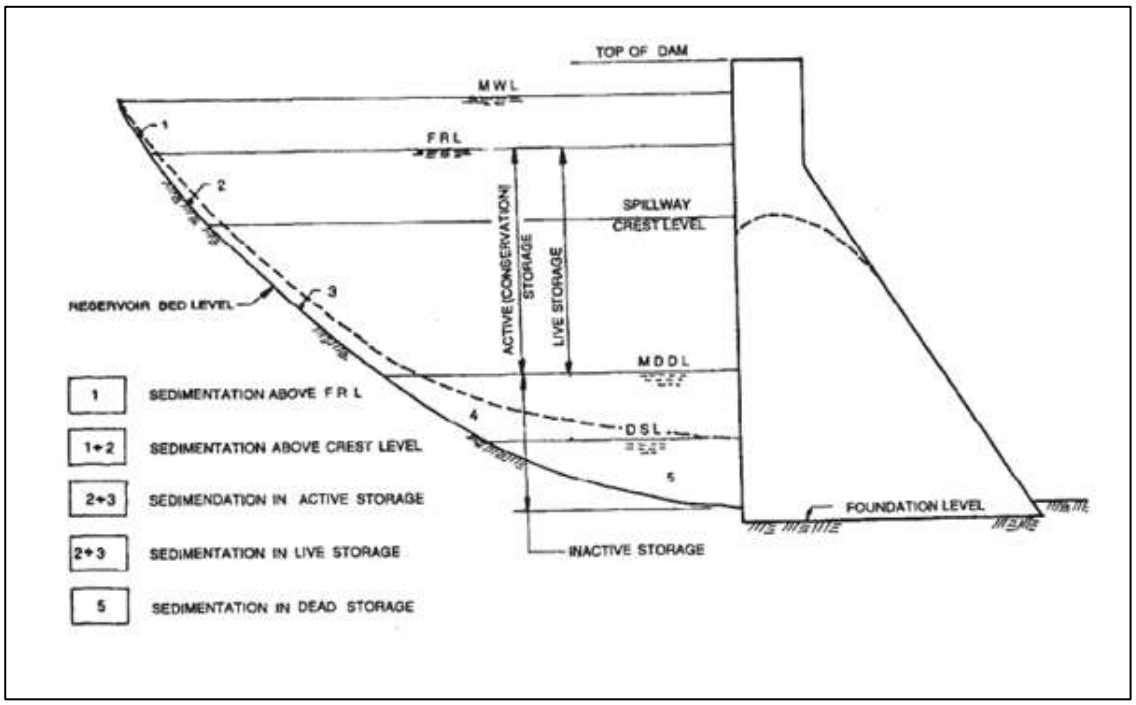


Figure 4.2: Sedimentation in different zones of reservoir (Ref: IS 5477-Part 1,1999)

The trap efficiency and the silt index has been calculated based on the methodology given in IS 12182, 1987. The gross capacity of reservoir as per present survey at FRL is 33.03 Mm^3 (1166.443 M cu ft) and client supplied Mean Annual inflow is 55 Mm^3. The values of trap efficiency are calculated using Brune's curve for the capacity inflow ratio for the reservoir. The silt index is calculated as the ratio of period of retention and flow velocity in the reservoir. The details of the calculations of period of retention and flow

velocity are given in standard codes such as IS 12182, 1987. The values are shown in Table 5.6.

At last, sedimentation volumes are compared with sedimentation volumes from previous year surveys and rate of sedimentation, loss of capacity as well as annual loss percentage is computed and compared with the values of previous years to arrive at meaningful conclusions. The sedimentation quantities as well as loss of storage capacities, rate of siltation as well as trap efficiency and sedimentation index are shown in Section 5.3.

The Sedimentation rate and Annual % loss is calculated using the equations (3) and (4)

$$\textit{Sedimentation rate (Ha m/ 100 Sq km/year)} = \frac{100 * \text{loss of gross capacity (Ha m)}}{\text{Catchment Area (Sq km)} * \text{Number of years between the surveys}} \quad (3)$$

$$\textit{Annual \% loss} = \frac{\text{Sedimentation rate (M cu m)}}{\text{Original Gross capacity of reservoir (M cu m)}} \text{x}100 \quad (4)$$

4.6 Charting the Results of Bathymetry and Topography Data

- Chart showing reservoir bed heights are provided for the current survey at 1:5000 scale.
- Chart showing contour map at 1 m interval for Patadungri reservoir is also provided at 1:5000 scale.
- Chart showing reservoir bed relief image prepared from bathymetry and topography survey data is provided at 1:5000 scale.
- L-section of the reservoir and C-section at 100 m interval are provided as soft copy.

The results of the survey were submitted as per the documents in the 'List of Deliverables' placed at Appendix G.

5. Survey Results – Patadungri Reservoir

Survey results are detailed in the following sections. The following text should be read in conjunction with the Charts as listed in Appendix G to this document.

Data acquisition for Patadungri reservoir was carried out up to Full Supply Level (FSL) of 170.84 m (560.5 ft).

5.1 Reservoir Bed Heights

The lowest reservoir bed level was found at the upstream face of the dam & it becomes less deeper as we go further upstream from the dam face.

The reservoir topography was uneven with reservoir bed level ranging from 157.8 m (517.7 ft) to 170.84 m (560.5 ft) w.r.t. client supplied TBM.

The reservoir bed tends to get shallower as we go further towards east, west, south and north-east direction away from the reservoir centre within the survey area. At some of the places shallow patches/islands/isolated land bodies/vegetation were observed within the survey area. One such small patch of island was observed approximately at centre of the reservoir.

Lowest reservoir bed level recorded was 157.8 m (517.7 ft) w.r.t. client supplied TBM (426 618 mE, 2 513 175 mN), within the survey area.

Highest reservoir bed level recorded was 170.84 m (560.5 ft) w.r.t. client supplied TBM (427 500 mE, 2 513 152mN) within the survey area.

The following figures show the gridded bathymetry and topography data for the Patadungri reservoir.

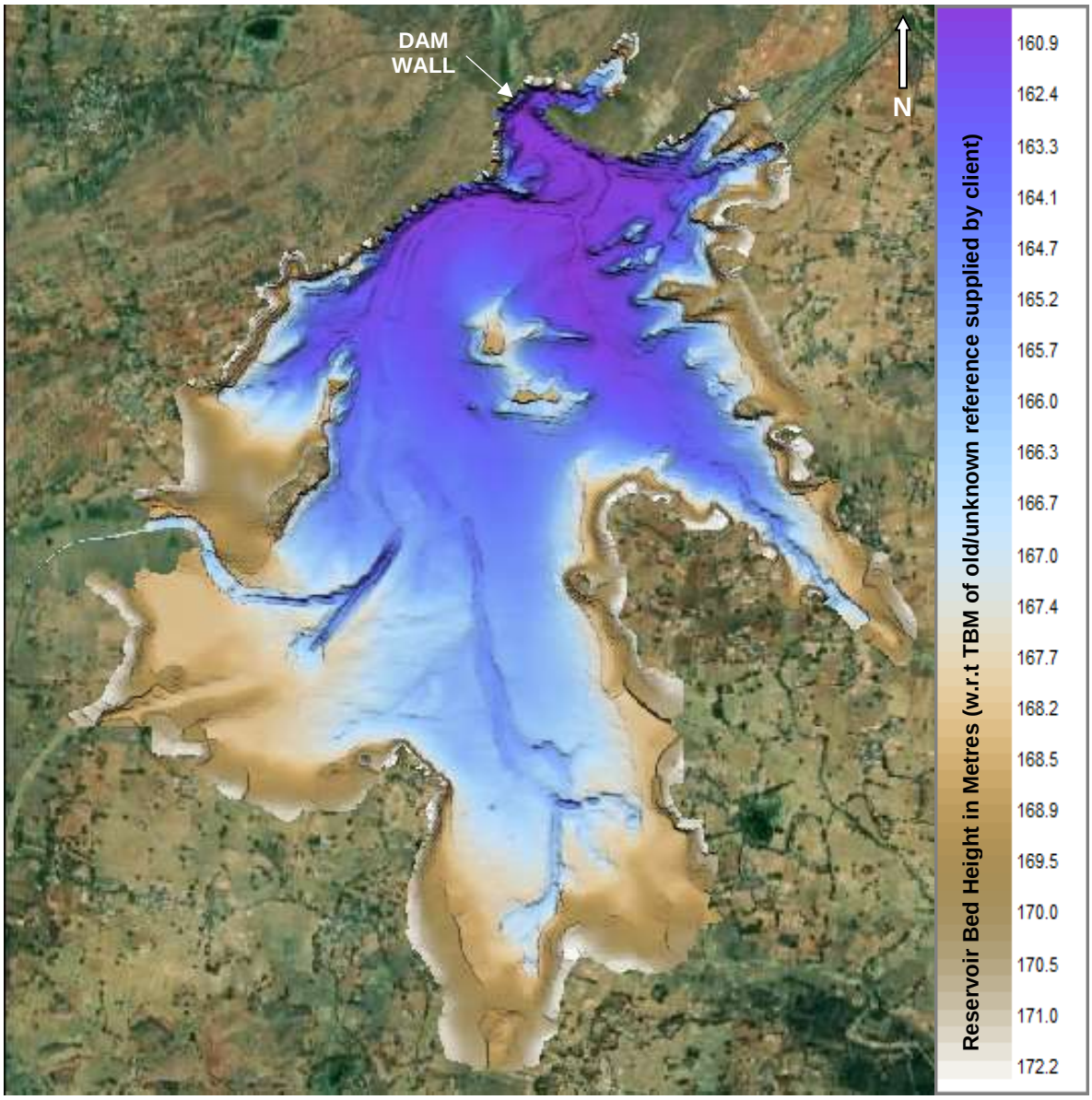


Figure 5.1: Image showing gridded SBES Bathymetry and topography data of reservoir bed heights (superimposed with satellite imagery) in metres from lowest bed level to FSL.

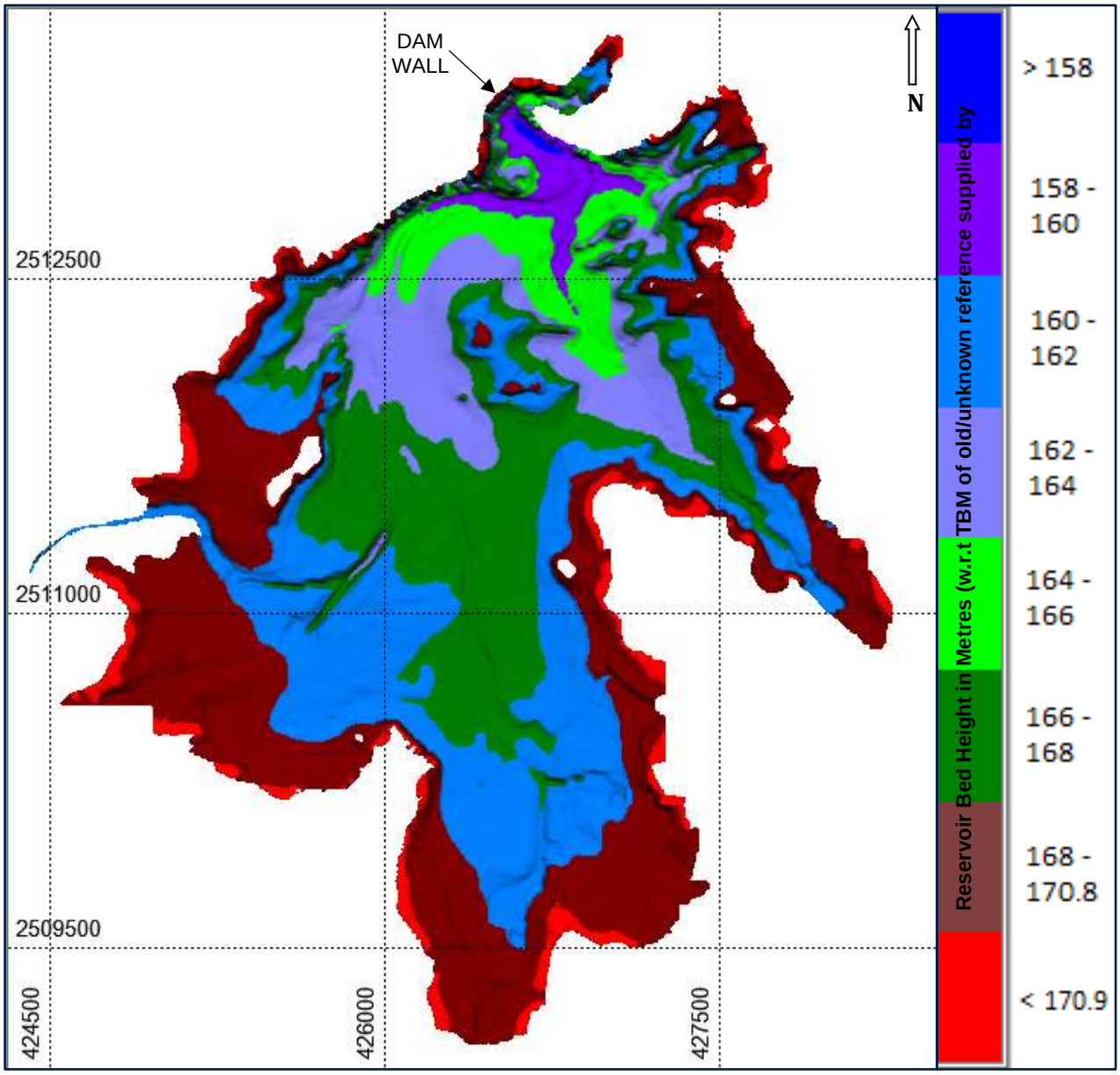


Figure 5.2: Shaded relief image showing gridded SBES Bathymetry and topography data of reservoir bed heights in metres from lowest bed level to FSL.

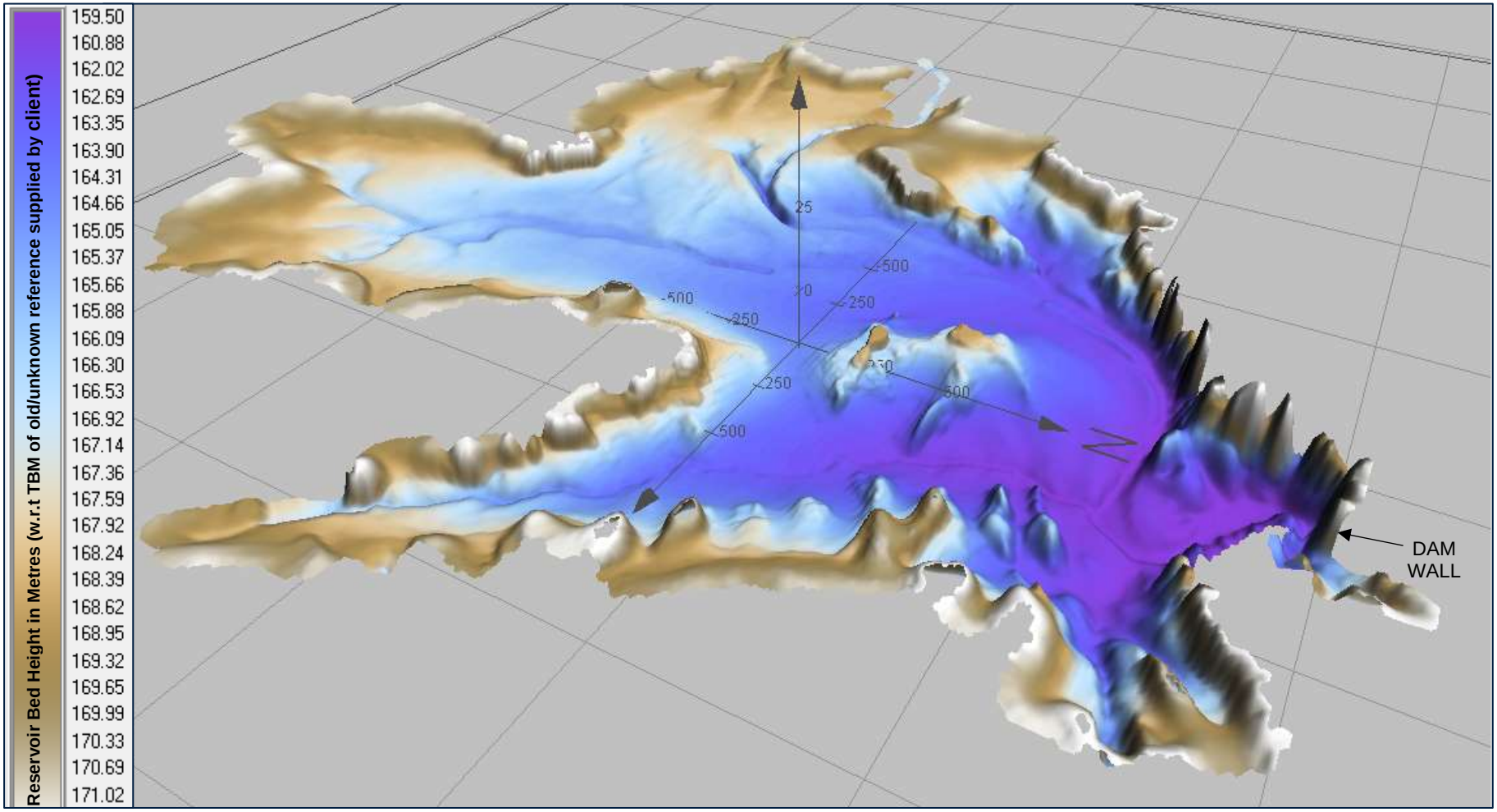


Figure 5.3: 3D view of Patadungri Reservoir

Photograph A: South-east side of the Patadungri dam wall (427086 mE, 2512620.1 mN) showing an isolated island within Patadungri Reservoir

Photograph B: South side of the Patadungri dam wall (426549 mE,2512889 mN) showing an area with shallow water depth & submerged vegetation within Patadungri Reservoir.

Photograph C: Central part Patadungri Reservoir (426431 mE, 2512282 mN) showing an area with shallow water depth and submerged vegetation within Patadungri Reservoir.

Photograph D: Eastern part of Patadungri Reservoir (427419 mE, 2511582 mN) showing an island with rocky terrain within Patadungri Reservoir.

Figure 5.4: Photographs A, B, C and D showing areas of shallow water depths, islands and vegetation within Patadungri Reservoir.

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5.2 Elevation Area Capacity Curve (2020-2021)

The area and capacity of the Patadungri reservoir was tabulated against the respective increasing elevation starting from zero bed elevation i.e 157.8 m (517.7 ft) up to FSL 170.84 m (560.5 ft) at an increment of 0.1 m as shown in Table 5.1

Table 5.1: Revised Elevation Area Capacity table at every 0.1 m interval starting from Lowest bed level to FSL for the Survey Year 2020-2021

Elevation Area Capacity Table (2020-2021): Patadungri Dam			
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mcumtr]
1	157.80	0.002	0.000
2	157.90	0.007	0.000
3	158.00	0.011	0.001
4	158.10	0.019	0.003
5	158.20	0.025	0.005
6	158.30	0.034	0.008
7	158.40	0.044	0.012
8	158.50	0.053	0.017
9	158.60	0.060	0.022
10	158.70	0.065	0.029
11	158.80	0.069	0.035
12	158.90	0.074	0.042
13	159.00	0.080	0.050
14	159.10	0.086	0.058
15	159.20	0.094	0.067
16	159.30	0.102	0.077
17	159.40	0.114	0.088
18	159.50	0.126	0.100
19	159.60	0.136	0.113
20	159.70	0.147	0.127
21	159.80	0.162	0.143
22	159.90	0.177	0.160
23	160.00	0.193	0.178
24	160.02	0.196	0.181
25	160.10	0.210	0.198
26	160.20	0.230	0.220
27	160.30	0.252	0.244
28	160.40	0.272	0.271
29	160.50	0.290	0.299
30	160.60	0.310	0.329
31	160.70	0.332	0.361
32	160.80	0.356	0.395
33	160.90	0.377	0.432

Elevation Area Capacity Table (2020-2021): Patadungri Dam			
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mcumtr]
34	161.00	0.398	0.471
35	161.10	0.417	0.511
36	161.20	0.439	0.554
37	161.30	0.460	0.599
38	161.40	0.481	0.646
39	161.50	0.502	0.695
40	161.60	0.522	0.746
41	161.70	0.544	0.800
42	161.80	0.568	0.855
43	161.90	0.593	0.913
44	162.00	0.622	0.974
45	162.10	0.656	1.038
46	162.20	0.691	1.105
47	162.30	0.726	1.176
48	162.40	0.761	1.250
49	162.50	0.799	1.328
50	162.60	0.843	1.411
51	162.70	0.892	1.497
52	162.80	0.933	1.589
53	162.90	0.972	1.684
54	163.00	1.009	1.783
55	163.10	1.045	1.885
56	163.20	1.083	1.992
57	163.30	1.121	2.102
58	163.40	1.159	2.216
59	163.50	1.200	2.334
60	163.60	1.241	2.456
61	163.70	1.285	2.582
62	163.80	1.332	2.713
63	163.90	1.384	2.849
64	164.00	1.440	2.990
65	164.10	1.499	3.137
66	164.20	1.563	3.290

Elevation Area Capacity Table (2020-2021): Patadungri Dam			
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mcumtr]
67	164.30	1.632	3.450
68	164.40	1.700	3.617
69	164.50	1.777	3.790
70	164.60	1.851	3.972
71	164.70	1.921	4.160
72	164.80	1.984	4.356
73	164.90	2.043	4.557
74	165.00	2.107	4.764
75	165.10	2.177	4.979
76	165.20	2.259	5.200
77	165.30	2.336	5.430
78	165.40	2.411	5.667
79	165.50	2.487	5.912
80	165.60	2.568	6.165
81	165.70	2.661	6.427
82	165.80	2.788	6.699
83	165.90	2.910	6.984
84	166.00	3.028	7.281
85	166.10	3.139	7.589
86	166.20	3.268	7.909
87	166.30	3.390	8.242
88	166.40	3.496	8.587
89	166.50	3.600	8.941
90	166.60	3.699	9.306
91	166.70	3.796	9.681
92	166.80	3.896	10.066
93	166.90	3.992	10.460
94	167.00	4.097	10.864
95	167.10	4.211	11.280
96	167.20	4.325	11.707
97	167.30	4.442	12.145
98	167.40	4.555	12.595
99	167.50	4.670	13.056
100	167.60	4.772	13.528
101	167.70	4.857	14.010
102	167.80	4.911	14.498
103	167.90	4.959	14.991
104	168.00	5.010	15.490
105	168.10	5.067	15.994
106	168.20	5.145	16.504
107	168.30	5.370	17.030

Elevation Area Capacity Table (2020-2021): Patadungri Dam			
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mcumtr]
108	168.40	5.490	17.573
109	168.50	5.601	18.128
110	168.60	5.693	18.692
111	168.70	5.768	19.265
112	168.80	5.837	19.846
113	168.90	5.898	20.432
114	169.00	5.961	21.025
115	169.10	6.019	21.624
116	169.20	6.076	22.229
117	169.30	6.140	22.840
118	169.40	6.207	23.457
119	169.50	6.273	24.081
120	169.60	6.341	24.712
121	169.70	6.406	25.349
122	169.80	6.467	25.993
123	169.90	6.537	26.643
124	170.00	6.603	27.300
125	170.10	6.666	27.964
126	170.20	6.731	28.633
127	170.30	6.795	29.310
128	170.40	6.859	29.992
129	170.50	6.917	30.681
130	170.60	6.974	31.376
131	170.70	7.028	32.076
132	170.80	7.081	32.781
133	170.84	7.100	33.030
134	170.90	7.131	33.492

Comparison table between the elevation area capacity for the year 2020-21 with the elevation area capacity for the previous survey years of 1982-83 and 1954 (Original Project data) was prepared as shown Table 5.2 (in metric unit) and Table 5.3 (non-metric unit). Also, the comparison plots of capacity curve for the year 2020-2021, 1982-83, and 1954 (Project data) data are shown in

Figure 5.5 (in metric unit) and Figure 5.6 (non-metric unit).

Table 5.2: Comparison of Elevation Area Capacity data (in metric unit) for the years 2020-2021, 1982-83 and 1954 (Project data)

Sr. No	Elevation [m]	Survey in year 1954		Survey in year 1982-83		Survey in year 2020-21	
		Gross Capacity [Mcumtr]	Area [km^2]	Gross Capacity [Mcumtr]	Area [km^2]	Gross Capacity [Mcumtr]	Area [km^2]
1	160.0	1.416	0.754	--	--	0.178	0.193
2	161.5	2.888	1.202	--	--	0.695	0.502
3	163.1	5.805	1.828	--	--	1.885	1.045
4	164.6	9.203	2.934	--	--	3.972	1.851
5	165.0	--	--	9.631	2.857	4.764	2.107
6	166.1	13.592	3.883	--	--	7.589	3.139
7	166.4	--	--	12.544	3.573	8.587	3.496
8	167.6	19.822	4.868	18.981	4.730	13.528	4.772
9	169.2	27.751	5.844	26.391	5.544	22.229	6.076
10	170.7	39.219	9.967	37.350	9.506	32.076	7.028
11	170.84	41.059	10.129	39.038	9.652	33.030	7.100

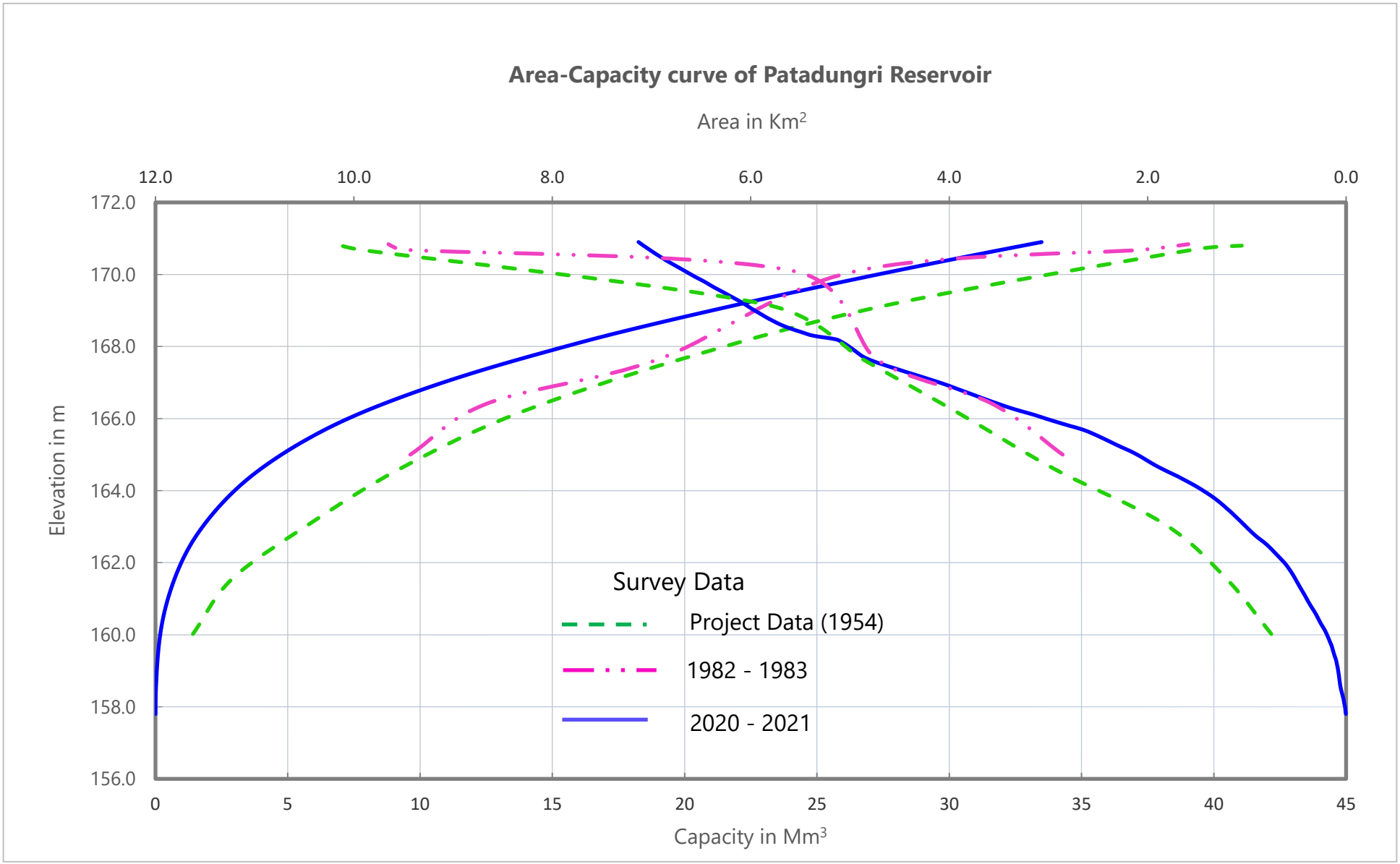

Figure 5.5: Area Capacity Curve of Patadungri Reservoir (in metric unit) for 1954, 1982—1983 and 2020-2021 surveys.

Table 5.3: Comparison of Elevation Area Capacity data (in non-metric unit) for the years 2020-2021, 1982-83 and 1954 (Project data)

Sr. No	Elevation [Ft]	Survey in year 1954		Survey in year 1982-83		Survey in year 2020-21	
		Gross Capacity [McuFt]	Area [Acre]	Gross Capacity [McuFt]	Area [Acre]	Gross Capacity [McuFt]	Area [Acre]
1	525.0	50.00	186.20	--	--	6.288	47.705
2	530.0	102.00	297.10	--	--	24.552	123.936
3	535.0	205.00	451.70	--	--	66.584	258.307
4	540.0	325.00	725.00	--	--	140.264	457.410
5	541.3	--	--	340.10	706.00	168.256	520.578
6	545.0	480.00	959.60	--	--	268.004	775.636
7	546.0	--	--	443.00	883.00	303.230	863.904
8	550.0	700.00	1203.00	670.30	1170.00	477.741	1179.141
9	555.0	980.00	1444.00	931.99	1370.00	785.012	1501.423
10	560.0	1385.00	2463.00	1319.00	2349.00	1132.745	1736.551
11	560.5	1450.00	2503.00	1378.61	2385.00	1166.443	1754.447

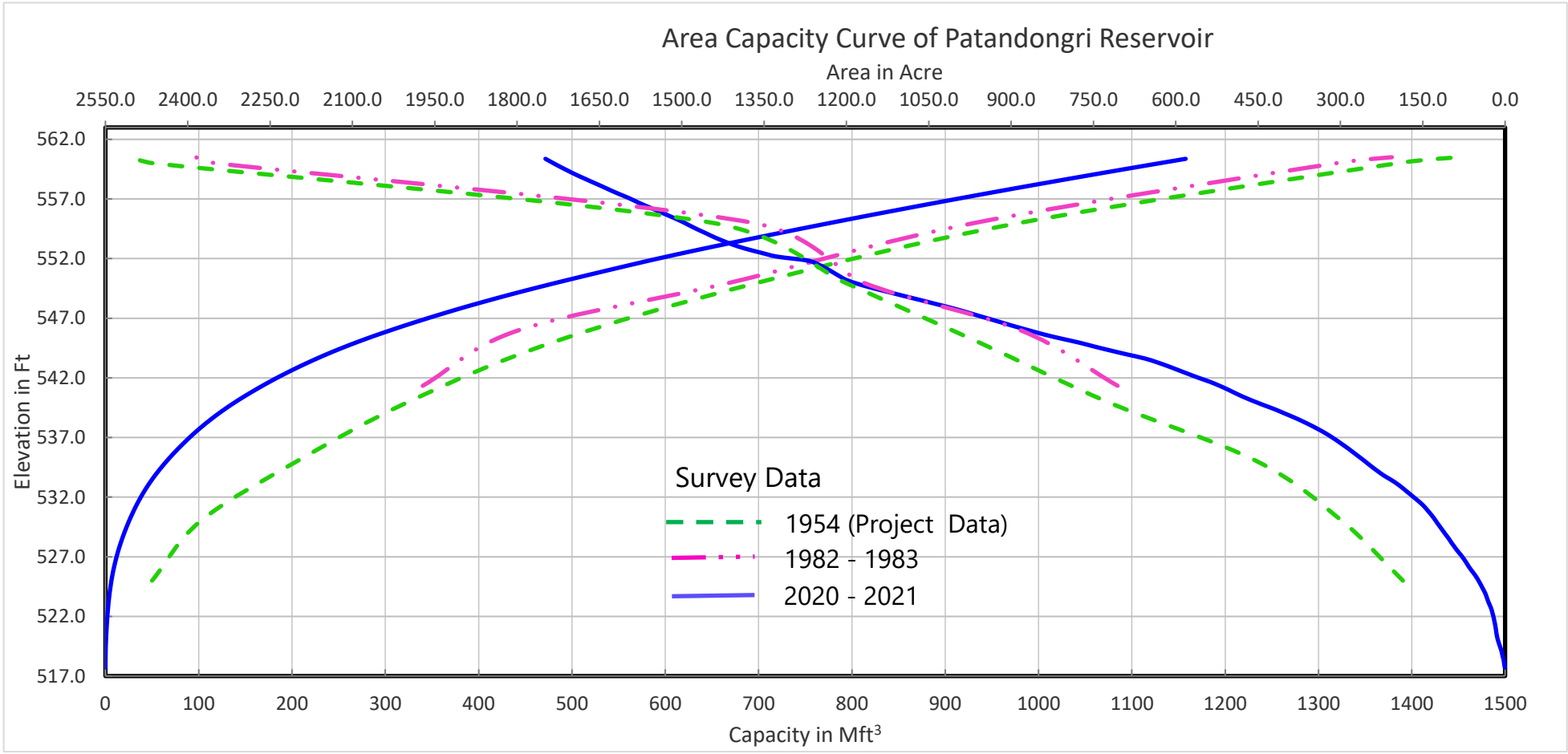

Figure 5.6: Area Capacity Curve of Patadungri Reservoir (in non-metric unit) for 1954, 1982—1983 and 2020-2021 surveys.

5.3 Sedimentation in Reservoir

The present survey of Patadungri reservoir was carried out between March 2021 and April 2021. Previous survey was carried out in the year 1982-83. The catchment area considered for sedimentation studies is 249 km^2. In the present study, the age of the reservoir is considered as 67 years (1954 – 2021). As per 2020-2021 survey, the total area of the reservoir at FSL 170.84 m (560.5 ft) is 7.100 km^2 (1754.447 Acre) and the corresponding storage capacity is 33.030 Mm^3 (1166.443 M cu ft). Table 5.4 (in metric unit) and Note: 1982-83 data is not compared because dead storage is not known. Capacity between 165.0 m and 170.84 m is only given in client supplied document

Table 5.5 (in non-metric unit) details the capacity loss, rate of sedimentation and annual % loss in gross storage capacity w.r.t. Original project capacity (1954) and 1982-83 capacity survey results.

Table 5.4: Sedimentation in Patadungri Reservoir (in metric unit)

Year	1954	2020-21
Storage Capacity in Mm^3		
Dead	1.416	0.181
Live	39.643	32.849
Gross	41.059	33.030
Loss of Storage Capacity in Mm^3		(wrt 1954)
Dead	NA	1.235
Live	NA	6.794
Gross	NA	8.029
Sedimentation Rate in Ham/100 km^2/Year		(wrt 1954)
Dead	NA	0.740
Live	NA	4.072
Gross	NA	4.813
Annual % loss		(wrt 1954)
Dead	NA	0.045
Live	NA	0.247
Gross	NA	0.292
Class of reservoir as per IS -12182 (1987)	As per design	Significant
Volume of sediment (w.r.t. 1954) deposited on bed in 2020-21= Loss of storage capacity= 8.029 Mm^3		
Note: Sign Convention: -ve sign shows desiltation and +ve sign shows siltation		

Note: 1982-83 data is not compared because dead storage is not known. Capacity between 165.0 m and 170.84 m is only given in client supplied document

Table 5.5: Sedimentation in Patadungri Reservoir (in non-metric unit)

Year	1954	2020-21
Storage Capacity in Mft^3		
Dead	50.0	6.392
Live	1400.0	1160.051
Gross	1450.0	1166.443
Loss of Storage Capacity in Mft^3		(wrt 1954)
Dead	NA	43.614
Live	NA	239.928
Gross	NA	283.541
Sedimentation Rate in Acre-ft/100 mi^2/Year		(wrt 1954)
Dead	NA	15.544
Live	NA	85.510
Gross	NA	101.054
Annual % loss		(wrt 1954)
Dead	NA	0.045
Live	NA	0.247
Gross	NA	0.292
Class of reservoir as per IS -12182 (1987)	As per design	Significant
Volume of sediment (w.r.t. 1954) deposited on bed in 2020-21= Loss of storage capacity= 283.541 Mft^3		
Note: Sign Convention: -ve sign shows desiltation and +ve sign shows siltation		

Note: 1982-83 data is not compared because dead storage is not known. Capacity between 541.3 ft and 560.5 ft is only given in client supplied document

Table 5.6 gives the results of the Trap efficiency and Sedimentation Index calculated for Patadungri reservoir as per the methodology given in IS 12182-1987.

Table 5.6: Trap Efficiency and Sedimentation Index for Patadungri Reservoir

Trap Efficiency	Sedimentation Index
96%	6.90×10^{10} s^2/m

In

Table 5.7, the Project data of 1954 was compared with 1982-83 and 2020-2021 survey results to understand the sedimentation in Patadungri reservoir. It may be observed that there is a consistent trend of siltation process happening over the lifespan of the reservoir. The results of 2020-21 survey indicate that, the volume of silt deposited has increased as compared to the 1982-83 survey. The reason behind siltation could be change of upstream catchment characteristics. Also, there could be some anthropogenic activities, which might be the cause for siltation.

Table 5.7: Sedimentation Volumes from Surveys of Previous Year

Sr. No.	Year of Survey	Source of Data	Period (years)	Gross Reservoir Capacity (Mm^3)	Loss of Gross Capacity (Since 1954 survey)			Observed Rate of Sedimentation Since 1954 survey (Ha m / 100 Sq km/Yr)
					Mm^3	% Cumulative	Remarks	
1	1954 (FSL)	Client	-	41.059	-	-	-	-
2	1982-83 (FSL)	Client	29	39.038	2.022	4.923	Siltation	2.799
3	2020-21 (FSL)	Present survey	67	33.030	8.029	19.556	Siltation	4.813
FSL – 170.84 m (560.5 ft)								

- As per 2020-2021 survey results, the volume of sediment deposited or the loss in gross storage capacity w.r.t. 1954 (Project data) is 8.029 Mm^3 (283.541 Mft^3).
- The rate of siltation in Patadungri reservoir is 0.120 Mm^3/year (97.29 Acre-ft/year).
- The observed average rate of siltation in the Patadungri reservoir during the 67 years life span (1954 – 2021), works out to 4.813 Ham/100 sq km/year (101.054 Acre-ft/100 mi^2/Year)
- The annual % loss in Patadungri reservoir during the 67 years life span is 0.292 % and hence, the reservoir is classified as "Significant category" as per IS 12182 (1987).
- Trap Efficiency and sedimentation Index calculated for Patadungri reservoir as per methodology give in IS 12182-1987 is 96% and 6.90 x 10^{10} s^2/m respectively.

Table 5.8 gives the details of revised Gross, Live and Dead storage capacity of Patadungri reservoir at every 0.1 m interval starting from lowest bed level to FRL (170.84 m)

Table 5.8: Gross, Live and Dead Storage Capacity of Reservoir at every 0.1 m interval starting from bed level to FSL 170.84 m

Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
1	157.80	0.000	--	0.000	Bed level
2	157.90	0.000	--	0.000	--
3	158.00	0.001	--	0.001	--
4	158.10	0.003	--	0.003	--
5	158.20	0.005	--	0.005	--
6	158.30	0.008	--	0.008	--
7	158.40	0.012	--	0.012	--
8	158.50	0.017	--	0.017	--
9	158.60	0.022	--	0.022	--
10	158.70	0.029	--	0.029	--
11	158.80	0.035	--	0.035	--
12	158.90	0.042	--	0.042	--
13	159.00	0.050	--	0.050	--

Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
14	159.10	0.058	--	0.058	--
15	159.20	0.067	--	0.067	--
16	159.30	0.077	--	0.077	--
17	159.40	0.088	--	0.088	--
18	159.50	0.100	--	0.100	--
19	159.60	0.113	--	0.113	--
20	159.70	0.127	--	0.127	--
21	159.80	0.143	--	0.143	--
22	159.90	0.160	--	0.160	--
23	160.00	0.178	--	0.178	--
24	160.02	0.181	--	0.181	MDDL
25	160.10	0.198	0.017	0.181	--
26	160.20	0.220	0.039	0.181	--
27	160.30	0.244	0.063	0.181	--
28	160.40	0.271	0.090	0.181	--
29	160.50	0.299	0.118	0.181	--
30	160.60	0.329	0.148	0.181	--
31	160.70	0.361	0.180	0.181	--
32	160.80	0.395	0.214	0.181	--
33	160.90	0.432	0.251	0.181	--
34	161.00	0.471	0.290	0.181	--
35	161.10	0.511	0.330	0.181	--
36	161.20	0.554	0.373	0.181	--
37	161.30	0.599	0.418	0.181	--
38	161.40	0.646	0.465	0.181	--
39	161.50	0.695	0.514	0.181	--
40	161.60	0.746	0.565	0.181	--
41	161.70	0.800	0.619	0.181	--
42	161.80	0.855	0.674	0.181	--
43	161.90	0.913	0.732	0.181	--
44	162.00	0.974	0.793	0.181	--
45	162.10	1.038	0.857	0.181	--
46	162.20	1.105	0.924	0.181	--
47	162.30	1.176	0.995	0.181	--
48	162.40	1.250	1.069	0.181	--
49	162.50	1.328	1.147	0.181	--
50	162.60	1.411	1.230	0.181	--
51	162.70	1.497	1.316	0.181	--
52	162.80	1.589	1.408	0.181	--

Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
53	162.90	1.684	1.503	0.181	--
54	163.00	1.783	1.602	0.181	--
55	163.10	1.885	1.704	0.181	--
56	163.20	1.992	1.811	0.181	--
57	163.30	2.102	1.921	0.181	--
58	163.40	2.216	2.035	0.181	--
59	163.50	2.334	2.153	0.181	--
60	163.60	2.456	2.275	0.181	--
61	163.70	2.582	2.401	0.181	--
62	163.80	2.713	2.532	0.181	--
63	163.90	2.849	2.668	0.181	--
64	164.00	2.990	2.809	0.181	--
65	164.10	3.137	2.956	0.181	--
66	164.20	3.290	3.109	0.181	--
67	164.30	3.450	3.269	0.181	--
68	164.40	3.617	3.436	0.181	--
69	164.50	3.790	3.609	0.181	--
70	164.60	3.972	3.791	0.181	--
71	164.70	4.160	3.979	0.181	--
72	164.80	4.356	4.175	0.181	--
73	164.90	4.557	4.376	0.181	--
74	165.00	4.764	4.583	0.181	--
75	165.10	4.979	4.798	0.181	--
76	165.20	5.200	5.019	0.181	--
77	165.30	5.430	5.249	0.181	--
78	165.40	5.667	5.486	0.181	--
79	165.50	5.912	5.731	0.181	--
80	165.60	6.165	5.984	0.181	--
81	165.70	6.427	6.246	0.181	--
82	165.80	6.699	6.518	0.181	--
83	165.90	6.984	6.803	0.181	--
84	166.00	7.281	7.100	0.181	--
85	166.10	7.589	7.408	0.181	--
86	166.20	7.909	7.728	0.181	--
87	166.30	8.242	8.061	0.181	--
88	166.40	8.587	8.406	0.181	--
89	166.50	8.941	8.760	0.181	--
90	166.60	9.306	9.125	0.181	--
91	166.70	9.681	9.500	0.181	--

Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
92	166.80	10.066	9.885	0.181	--
93	166.90	10.460	10.279	0.181	--
94	167.00	10.864	10.683	0.181	--
95	167.10	11.280	11.099	0.181	--
96	167.20	11.707	11.526	0.181	--
97	167.30	12.145	11.964	0.181	--
98	167.40	12.595	12.414	0.181	--
99	167.50	13.056	12.875	0.181	--
100	167.60	13.528	13.347	0.181	--
101	167.70	14.010	13.829	0.181	--
102	167.80	14.498	14.317	0.181	--
103	167.90	14.991	14.810	0.181	--
104	168.00	15.490	15.309	0.181	--
105	168.10	15.994	15.813	0.181	--
106	168.20	16.504	16.323	0.181	--
107	168.30	17.030	16.849	0.181	--
108	168.40	17.573	17.392	0.181	--
109	168.50	18.128	17.947	0.181	--
110	168.60	18.692	18.511	0.181	--
111	168.70	19.265	19.084	0.181	--
112	168.80	19.846	19.665	0.181	--
113	168.90	20.432	20.251	0.181	--
114	169.00	21.025	20.844	0.181	--
115	169.10	21.624	21.443	0.181	--
116	169.20	22.229	22.048	0.181	--
117	169.30	22.840	22.659	0.181	--
118	169.40	23.457	23.276	0.181	--
119	169.50	24.081	23.900	0.181	--
120	169.60	24.712	24.531	0.181	--
121	169.70	25.349	25.168	0.181	--
122	169.80	25.993	25.812	0.181	--
123	169.90	26.643	26.462	0.181	--
124	170.00	27.300	27.119	0.181	--
125	170.10	27.964	27.783	0.181	--
126	170.20	28.633	28.452	0.181	--
127	170.30	29.310	29.129	0.181	--
128	170.40	29.992	29.811	0.181	--
129	170.50	30.681	30.500	0.181	--
130	170.60	31.376	31.195	0.181	--

Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
131	170.70	32.076	31.895	0.181	--
132	170.80	32.781	32.600	0.181	--
133	170.84	33.030	32.849	0.181	FSL

6. Conclusions

- The reservoir topography was uneven, with reservoir bed level ranging from 157.8 m (517.7 ft) to 170.84 m (560.5 ft) w.r.t. client supplied TBM. The lowest reservoir bed level 157.8 m (517.7 ft) was found near the upstream face of the dam boundary and it becomes shallower as we go further upstream from the dam face. Also, the reservoir bed tends to get shallower as we go further east, west, south and north-east direction from the reservoir centre.
- Through the elevation area capacity curves, it was found that the gross capacity has further decreased in year 2020-21 as compared to 1982-83 (i.e. the volume of silt deposited has increased in the Patadungri reservoir). The probable reasons for the decrease of gross capacity could be change in hydrodynamics due to change of upstream discharges as sediment carrying capacity of the river and its tributaries. Moreover, the cause of changes could be anthropogenic intervention towards siltation of the reservoir. Also, there is a consistent trend of siltation process going on in the reservoir as observed from survey data of previous years and current survey.
- In comparison with 1982-83 survey results, 2020-2021 results indicate further decrease in storage capacity due to siltation. However, w.r.t. 1954 Project Capacity data, siltation of Patadungri reservoir has taken place and the annual % loss in gross storage capacity is 0.292 % and hence, the reservoir is classified as “Significant category” as per IS 12182 (1987).
- The sedimentation volumes, sedimentation rates, loss of storage capacity, trap efficiency, sedimentation index have been reported in the study. Moreover, the tables for gross storage capacity of reservoir at every 0.1 m interval have been provided.

7. References

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Appendix A

Diary of Events

(01 page)

Diary of Events (Bathymetry and Topography Survey)	
Date	**Events**
Bathymetry Survey	
03 March 2021	Fugro personnel for survey boat 'Polaris' reached Patadungri Dam and survey boat deployed in water.
04 March 2021	Mobilisation on Polaris started.
05 March 2021	Mobilisation was completed and calibration started.
06 March 2021	Calibration completed and survey started.
06 March 2021	Bathymetry survey started.
07 March 2021	Bathymetry survey continued.
08 March 2021	Bathymetry survey continued.
09 March 2021	Bathymetry survey continued.
10 March 2021	Bathymetry survey continued.
11 March 2021	Bathymetry survey continued.
12 March 2021	Bathymetry survey continued.
13 March 2021	Bathymetry survey continued.
14 March 2021	Bathymetry survey continued.
15 March 2021	Bathymetry survey continued.
16 March 2021	Bathymetry survey continued.
17 March 2021	Bathymetry survey completed and demobilisation commenced.
18 March 2021	Demobilisation completed.
19 March 2021	Fugro personnel with Polaris boat proceeded towards Adalwada Dam.
Topography Survey	
07 April 2021	Topography survey team with equipment reached Patadungri Dam.
08 April 2021	Topography survey commenced
09 April 2021	Topography survey continued.
10 April 2021	Topography survey continued.
11 April 2021	Topography survey continued.
12 April 2021	Topography survey continued.
13 April 2021	Topography survey continued.
14 April 2021	Topography survey completed.

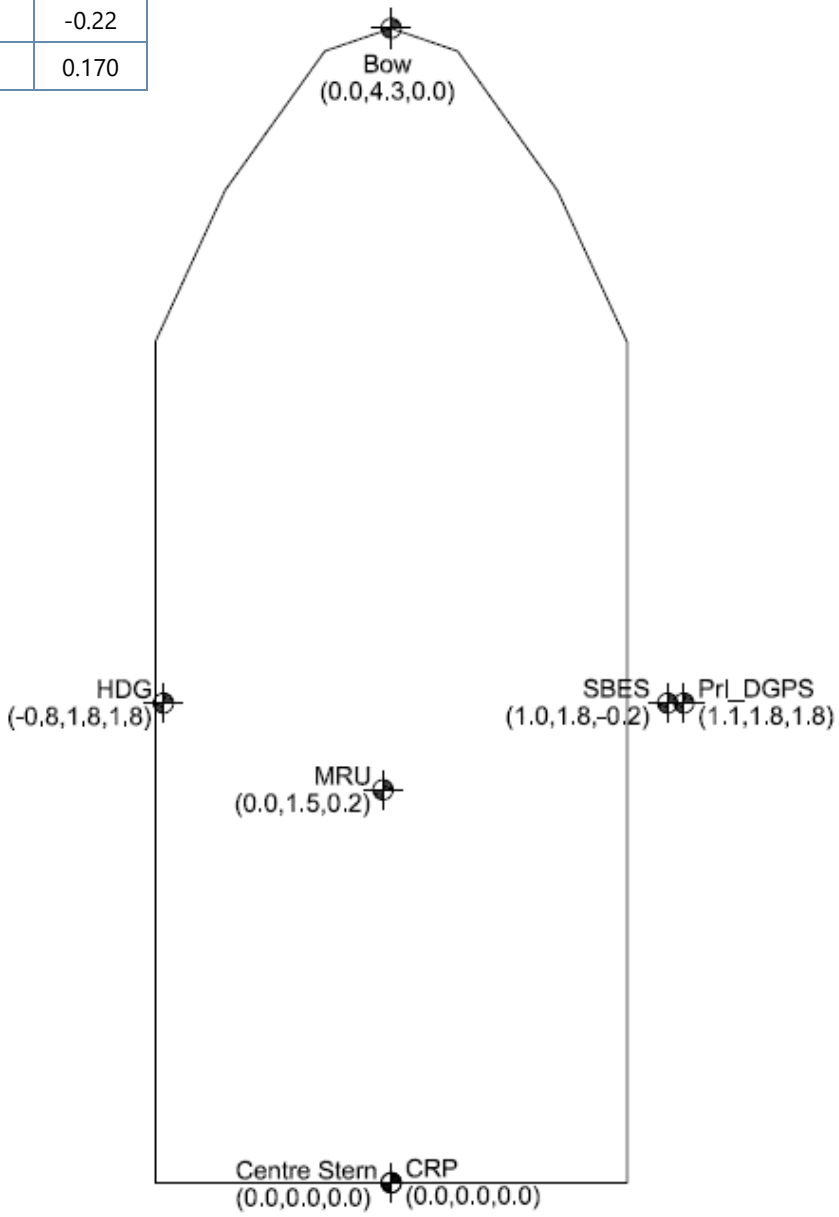
Appendix B

Survey Vessel Sensor Offsets

(01 page)

Survey Vessel 'Polaris' Sensor Offset Diagram

Sensor Offsets: Polaris			
Starfix.Suite Name	**X [m]**	**Y [m]**	**Z [m]**
CRP	0.00	0.00	0.00
Centre Stern	0.00	0.00	0.00
Bow	0.00	4.26	0.00
Pri_DGPS	1.08	1.77	1.82
HDG	-0.84	1.77	1.82
SBES	1.020	1.77	-0.22
MRU	-0.03	1.45	0.170

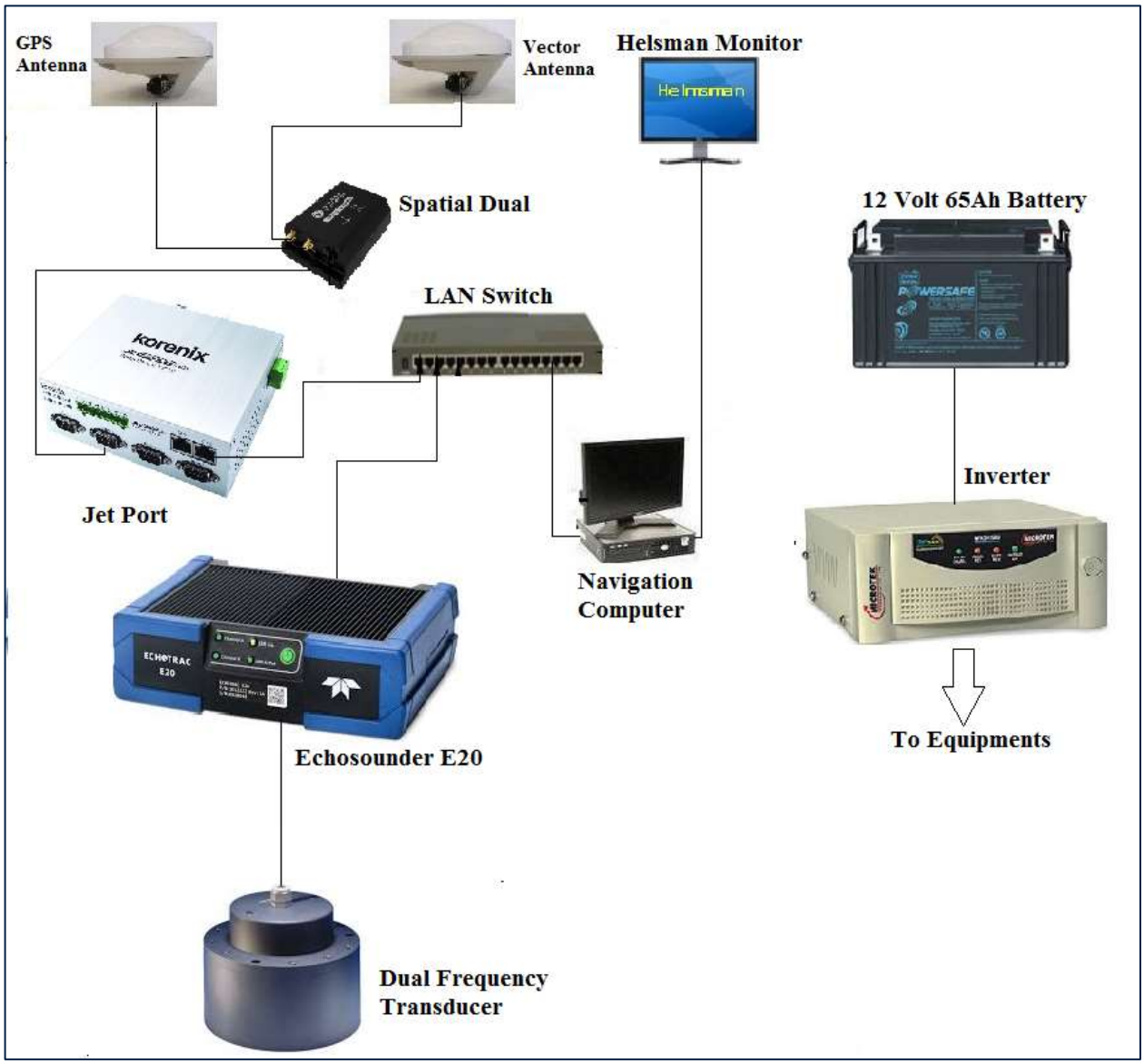


Appendix C

Equipment Layout Diagram

(01 page)

Equipment Layout Diagram onboard Polaris



Appendix D

Results of Field Calibrations / Verifications

(18 pages)

FUGRO SURVEY (INDIA) PVT. LTD.

Diagram Report of Patadungri-TBM

Job No. :	J-HYD-20-174630	**Job Name:**	Bathymetric Survey
Station Name:	Patadungri Dam	**Location:**	Gujarat, West Coast of India
Party Chief :	Arpit Bose	**Job Engineer/Surveyor :**	Mathiazhagan V.
Date of Observation: (Date & Time)	04-03-2021 & 13:12hrs	**End of Observation: (Date & Time)**	04-03-2021 & 13:42hrs

1. Station Name: Patadungri-TBM.

Positioning System Verification Results						
World Geodetic System 84, UTM Projection, CM 075° East, Zone 43 North						
Sensor	**Serial No.**	**Starfix.Seis Name**	**Method**	**File Type**	**Mean Differences**	**SD**
TRIMBLE BX992 RECEIVER	025-00009601	PRI_DGPS	Mean position report	FBF	NA	0.01

A= Patadungri-TBM Height is 170.050m/557.90ft

B= Antenna Height from BM 1.605m (Measured by Tape)

Ellipsoidal height of Antenna= 276.444m

Ellipsoidal Height of BM 276.444m-1.605m=274.839m

C is the center point of BM.

Position Of Antenna:-

Latitude: 22°43'25.07059"N, **Longitude:** 74°17'44.47554"E

Easting: 4,27,673.6m E **Northing:** 25,13,098.021m N

Prepared By: Arpit Bose.

BATHY

MEAN POSITION REPORT

Project ID	patadungri		
Location	Central Gujarat		
Client	Narmada Water Resources Govt. of Gujarat	**Vessel**	Tripod
Comment			

Session Name: PATADUNGRI-TBM-v2 Records Used: 1015 of 1648

Start Time: 04 Mar 2021, 13:12:23+05:30 End Time: 04 Mar 2021, 13:42:22+05:30 Session Length: 00:29:59

Mean Position for Tripod CentreOfGravity		
	WGS 84 / UTM zone 43N	**WGS 84(2D)**
Latitude	22°43’25.07059”N	22°43’25.07059”N
Longitude	074°17’44.47554”E	074°17’44.47554”E
Height	276.444m Ell.	276.444m Ell.
Easting	4,27,673.600m E (SD: ±0.01m)	
Northing	25,13,098.021m N (SD: ±0.01m)	
Height	333.514m Ort. (SD: ±0.03m Ort.)	

Sensors	**Sensor Averages**	**SD**
Heading	0.00°T 0.00°G	±0.0°
Pitch		
Roll		
Depth (Sounder)	0.0m	±0.00m
Depth (Manual)	0.0m	N/A

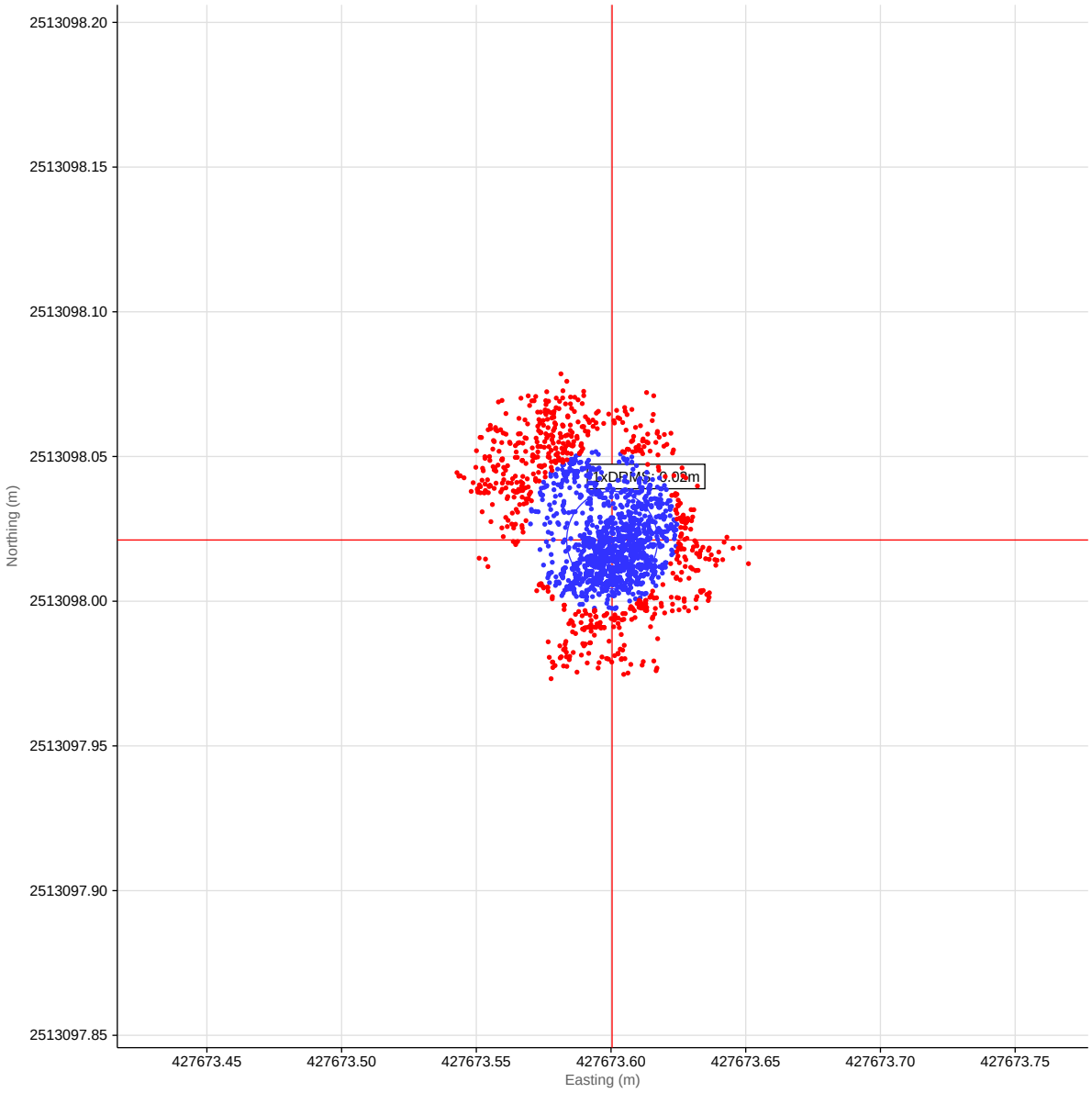
Arpit Bose
Party Chief
FSINPVT (Fugro Survey (India) Pvt Ltd.)

Section Officer
Client Representative
Narmada Water Resources Govt. of Gujarat

Geodetic Parameters

Name : WGS 84 / UTM zone 43N		
EPSG Code	EPSG::32643	
Local Geodetic Datum Parameters		
Datum	World Geodetic System 1984	EPSG::6326
Ellipsoid	WGS 84	
Semi major axis	a = 63,78,137.000 m	
Inverse flattening	1/f = 298.257223563	
Local Projection Parameters		
Map Projection	Transverse Mercator	
Grid System	UTM zone 43N	EPSG::16043
Latitude Origin	00° 00’ 00.000” N	
Central Meridian	075° 00’ 00.000” E	
Scale Factor on Central Meridian	0.9996	
False Easting	500 000 m	
False Northing	0 m	

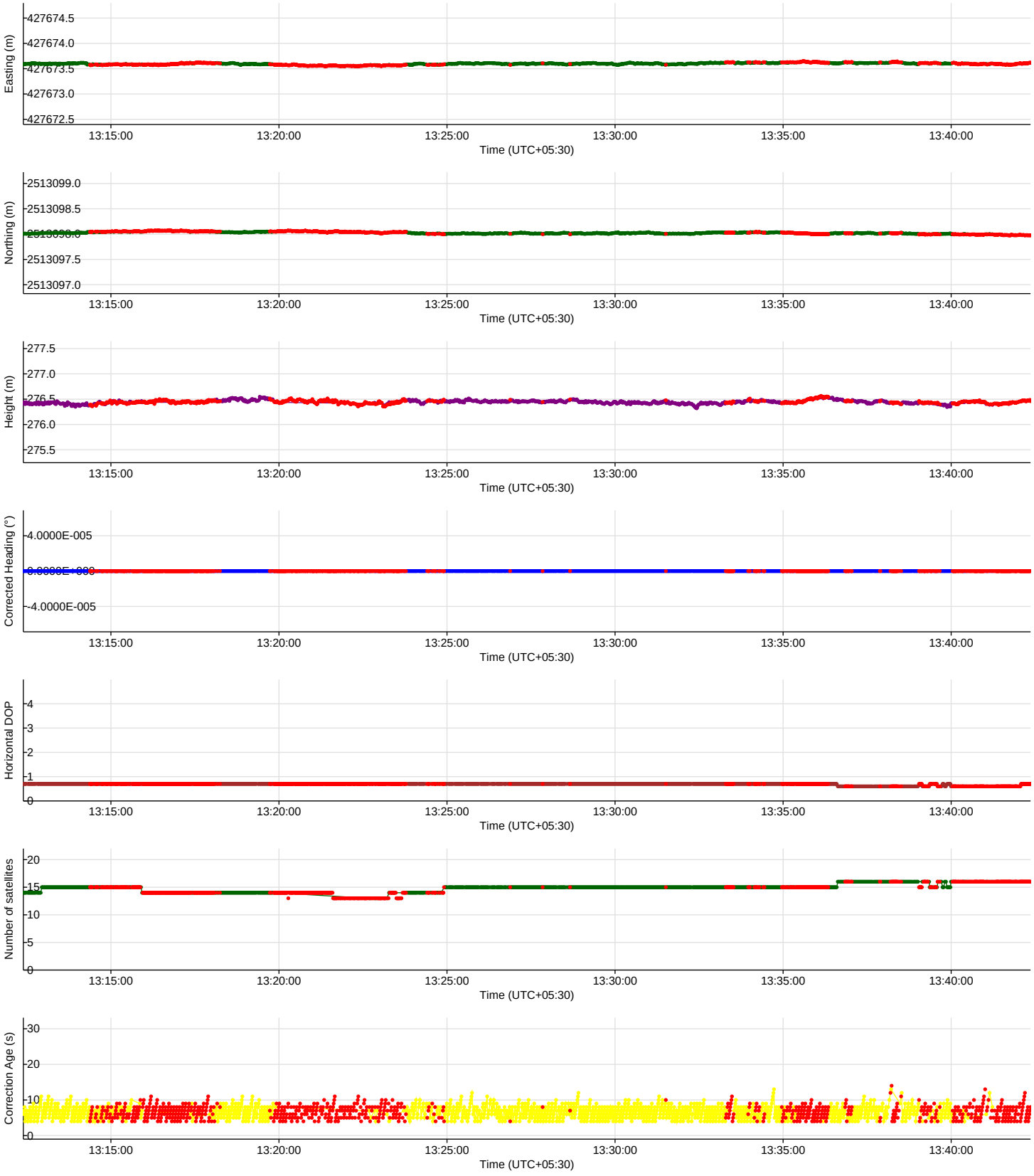
Scatter Plot



Mean Position

	Easting	Northing
Tripod	4,27,673.600m E	25,13,098.021m N

Time Series Plots for Tripod



FUGRO SURVEY (INDIA) PVT. LTD.

Diagram Report of Patadungri-TBM

Job No. :	J-HYD-20-174630	**Job Name:**	Bathymetric Survey
Station Name:	Patadungri Dam	**Location:**	Gujarat, West Coast of India
Party Chief :	Arpit Bose	**Job Engineer/Surveyor :**	Mathiazhagan V.
Date of Observation: (Date & Time)	04-03-2021 & 14:59hrs	**End of Observation: (Date & Time)**	04-03-2021 & 15:29hrs

1. Station Name: Patadungri-TBM.

Positioning System Verification Results						
World Geodetic System 84, UTM Projection, CM 075º East, Zone 43 North						
Sensor	**Serial No.**	**Starfix. Seis Name**	**Method**	**File Type**	**Mean Differences**	**SD**
SPATIAL DUAL RECIEVER	025-00006405	PRI_DGPS	Mean position report	FBF	NA	0.01

A= Patadungri-TBM Height 170.050m/557.90ft

B= Antenna Height from BM 1.595m (Measured by Tape)

Ellipsoidal height of Antenna= 276.423m

Ellipsoidal Height of BM 276.423m-1.595m=274.828m

C is the center point of BM.

Position Of Antenna:-

Latitude: 22°43’25.06715”N **Longitude:** 74°17’44.46743”E

Easting: 4,27,673.369m E **Northing:** 25,13,097.916m N

Prepared By: Arpit Bose.

BATHY

MEAN POSITION REPORT

Project ID	patadungri		
Location	Central Gujarat		
Client	Narmada Water Resources Govt. of Gujarat	**Vessel**	Tripod
Comment			

Session Name: PATADUNGRI-TBM-SPD-v1 Records Used: 1185 of 1799

Start Time: 04 Mar 2021, 14:59:16+05:30 End Time: 04 Mar 2021, 15:29:15+05:30 Session Length: 00:29:59

Mean Position for Tripod CentreOfGravity		
	WGS 84 / UTM zone 43N	**WGS 84(2D)**
Latitude	22°43’25.06715”N	22°43’25.06715”N
Longitude	074°17’44.46743”E	074°17’44.46743”E
Height	276.423m Ell.	276.423m Ell.
Easting	4,27,673.369m E (SD: ±0.01m)	
Northing	25,13,097.916m N (SD: ±0.01m)	
Height	333.494m Ort. (SD: ±0.05m Ort.)	

Sensors	**Sensor Averages**	**SD**
Heading	0.00°T 0.00°G	±0.0°
Pitch		
Roll		
Depth (Sounder)	0.0m	±0.00m
Depth (Manual)	0.0m	N/A

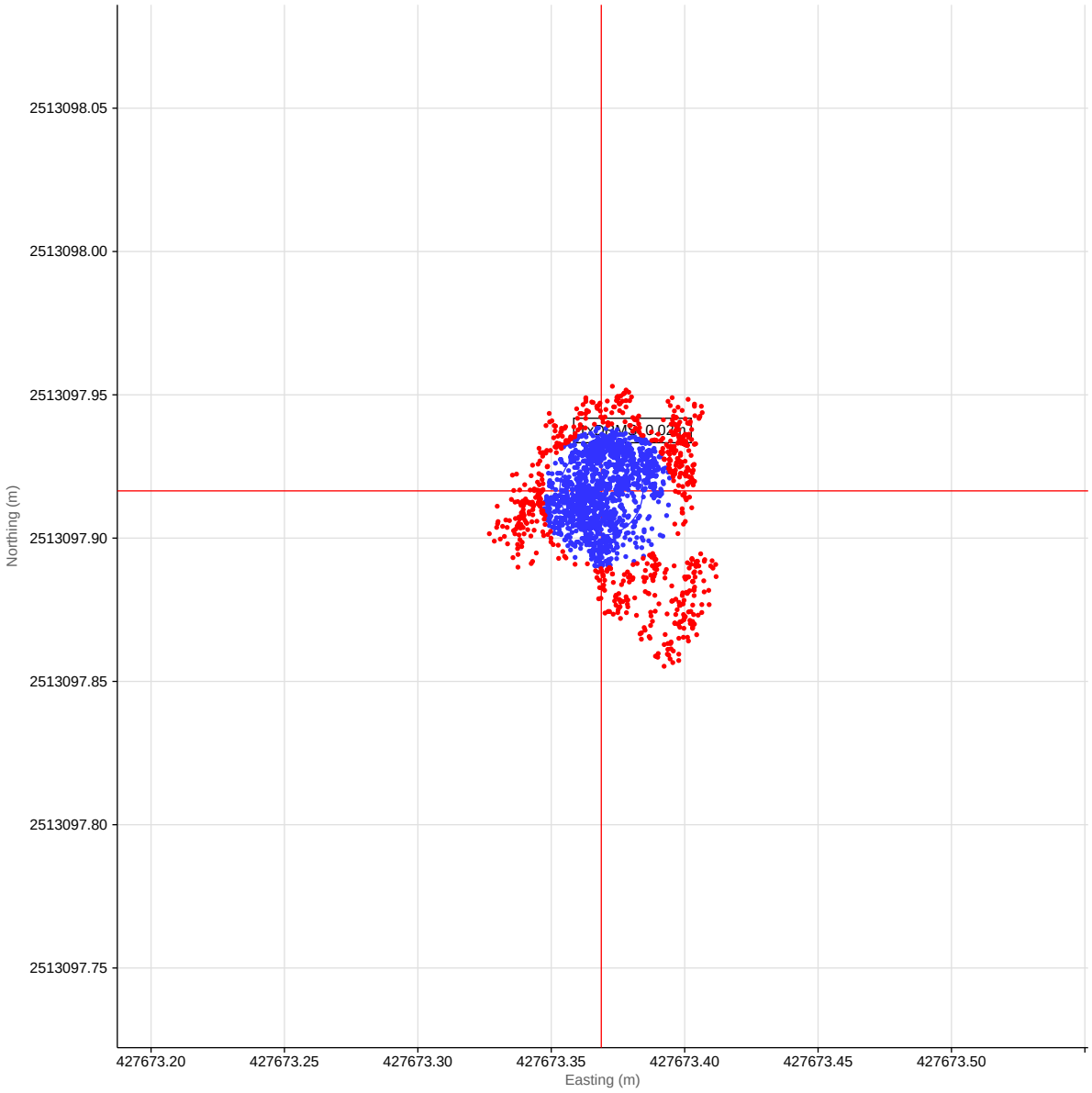
Arpit Bose
Party Chief
FSINPVT (Fugro Survey (India) Pvt Ltd.)

Section Officer
Client Representative
Narmada Water Resources Govt. of Gujarat

Geodetic Parameters

Name : WGS 84 / UTM zone 43N		
EPSG Code	EPSG::32643	
Local Geodetic Datum Parameters		
Datum	World Geodetic System 1984	EPSG::6326
Ellipsoid	WGS 84	
Semi major axis	a = 63,78,137.000 m	
Inverse flattening	1/f = 298.257223563	
Local Projection Parameters		
Map Projection	Transverse Mercator	
Grid System	UTM zone 43N	EPSG::16043
Latitude Origin	00° 00’ 00.000” N	
Central Meridian	075° 00’ 00.000” E	
Scale Factor on Central Meridian	0.9996	
False Easting	500 000 m	
False Northing	0 m	

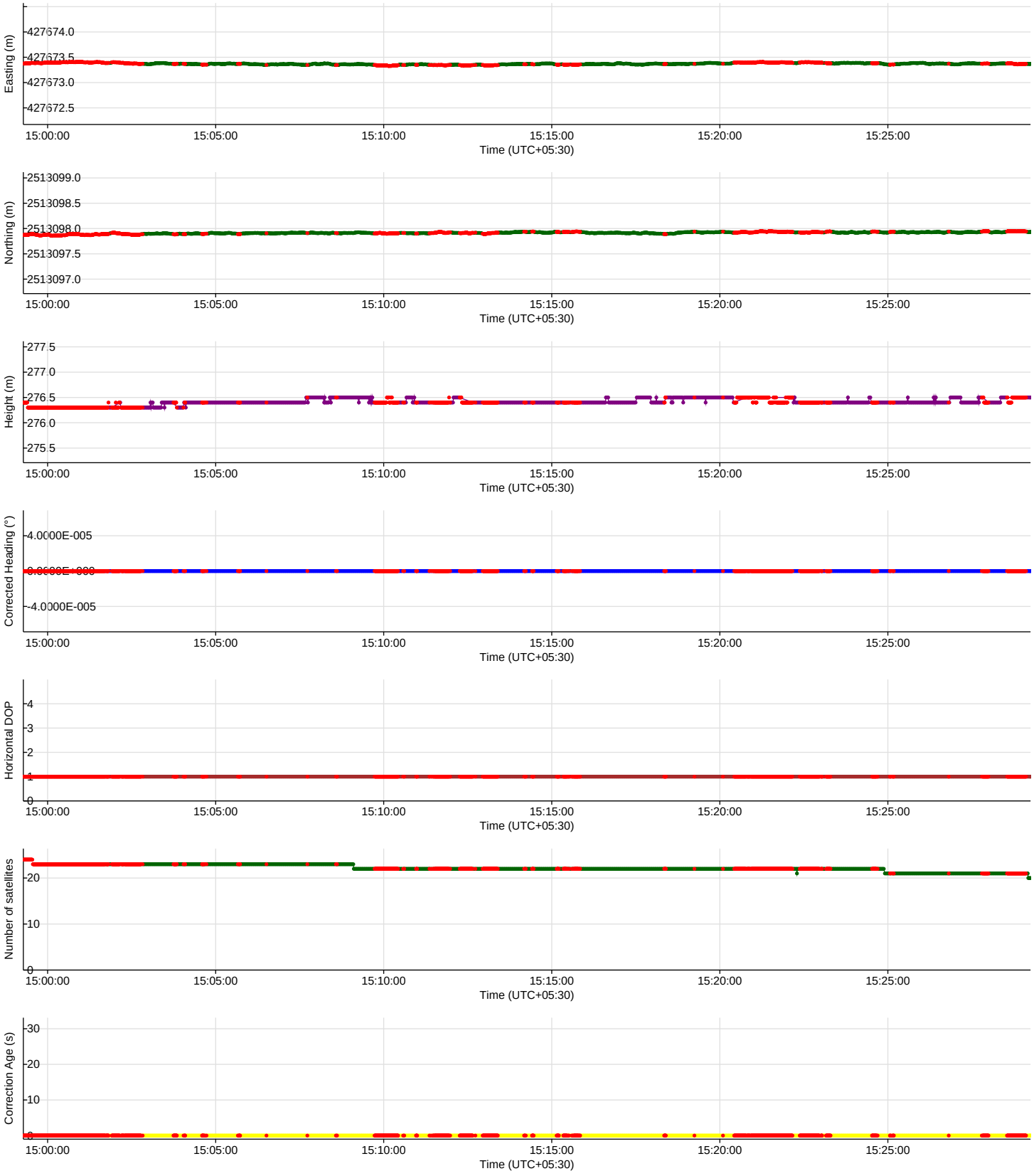
Scatter Plot



Mean Position

	Easting	Northing
Tripod	4,27,673.369m E	25,13,097.916m N

Time Series Plots for Tripod



FUGRO SURVEY (INDIA) PVT. LTD.

Diagram Report of TBM-03

Job No. :	J-HYD-20-174630	**Job Name:**	Bathymetric Survey
Station Name:	Machhanala Dam	**Location:**	Gujarat, West Coast of India
Party Chief :	Arpit Bose	**Job Engineer/Surveyor :**	Mathiazhagan V.
Date of Observation: (Date & Time)	05-03-2021 & 09:46hrs	**End of Observation: (Date & Time)**	05-03-2021 & 10:16hrs

1. Station Name: TBM-03.

Positioning System Verification Results						
World Geodetic System 84, UTM Projection, CM 075º East, Zone 43 North						
Sensor	**Serial No.**	**Starfix.Seis Name**	**Method**	**File Type**	**Mean Differences**	**SD**
TRIMBLE BX992 RECEIVER	025-00009601	PRI_DGPS	Mean position report	FBF	NA	0.01

A= TBM-02 Height from MSL 281.206m

B= Antenna Height from BM 0.53m (Measure by Tape)

Ellipsoidal height of Antenna= 281.206m

Ellipsoidal Height of BM 281.206m-0.530m=280.676m

C is the center point of BM.

Position Of Antenna:-

Latitude: 22°43’25.36992”N, **Longitude:** 74°17’44.76471”E

Easting: 4,27,681.893m E **Northing:** 25,13,107.186m N

Prepared By: Arpit Bose.

BATHY

MEAN POSITION REPORT

Project ID	patadungri		
Location	Central Gujarat		
Client	Narmada Water Resources Govt. of Gujarat	**Vessel**	Tripod
Comment			

Session Name: TBM-03-v1 Records Used: 1161 of 1800

Start Time: 05 Mar 2021, 09:46:34+05:30 End Time: 05 Mar 2021, 10:16:33+05:30 Session Length: 00:29:59

Mean Position for Tripod CentreOfGravity		
	WGS 84 / UTM zone 43N	**WGS 84(2D)**
Latitude	22°43’25.36992”N	22°43’25.36992”N
Longitude	074°17’44.76471”E	074°17’44.76471”E
Height	281.206m Ell.	281.206m Ell.
Easting	4,27,681.893m E (SD: ±0.02m)	
Northing	25,13,107.186m N (SD: ±0.01m)	
Height	338.277m Ort. (SD: ±0.04m Ort.)	

Sensors	**Sensor Averages**	**SD**
Heading	0.00°T 0.00°G	±0.0°
Pitch		
Roll		
Depth (Sounder)	0.0m	±0.00m
Depth (Manual)	0.0m	N/A

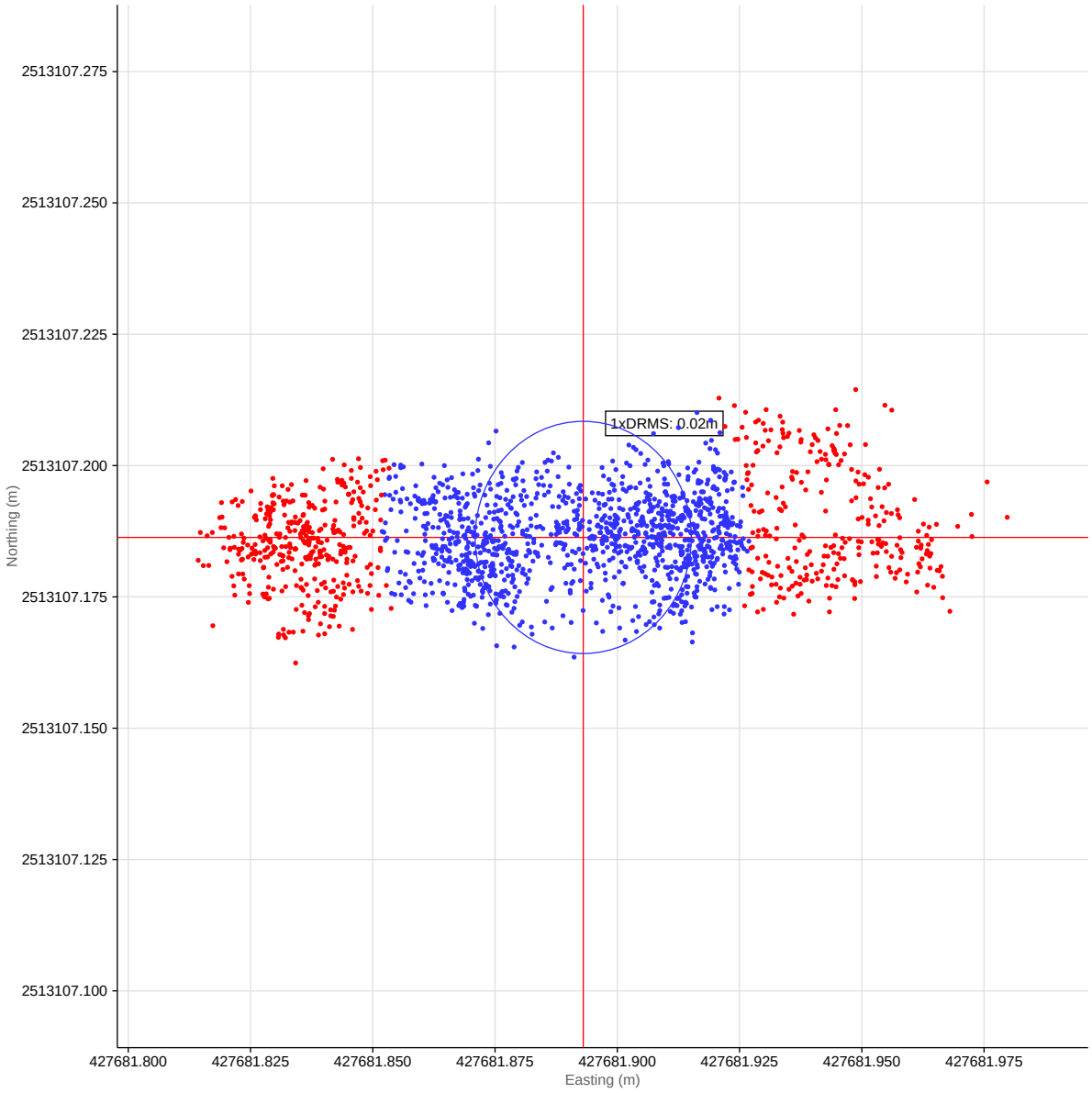
Arpit Bose
Party Chief
FSINPVT (Fugro Survey (India) Pvt Ltd.)

Section Officer
Client Representative
Narmada Water Resources Govt. of Gujarat

Geodetic Parameters

Name : WGS 84 / UTM zone 43N		
EPSG Code	EPSG::32643	
Local Geodetic Datum Parameters		
Datum	World Geodetic System 1984	EPSG::6326
Ellipsoid	WGS 84	
Semi major axis	a = 63,78,137.000 m	
Inverse flattening	1/f = 298.257223563	
Local Projection Parameters		
Map Projection	Transverse Mercator	
Grid System	UTM zone 43N	EPSG::16043
Latitude Origin	00° 00’ 00.000” N	
Central Meridian	075° 00’ 00.000” E	
Scale Factor on Central Meridian	0.9996	
False Easting	500 000 m	
False Northing	0 m	

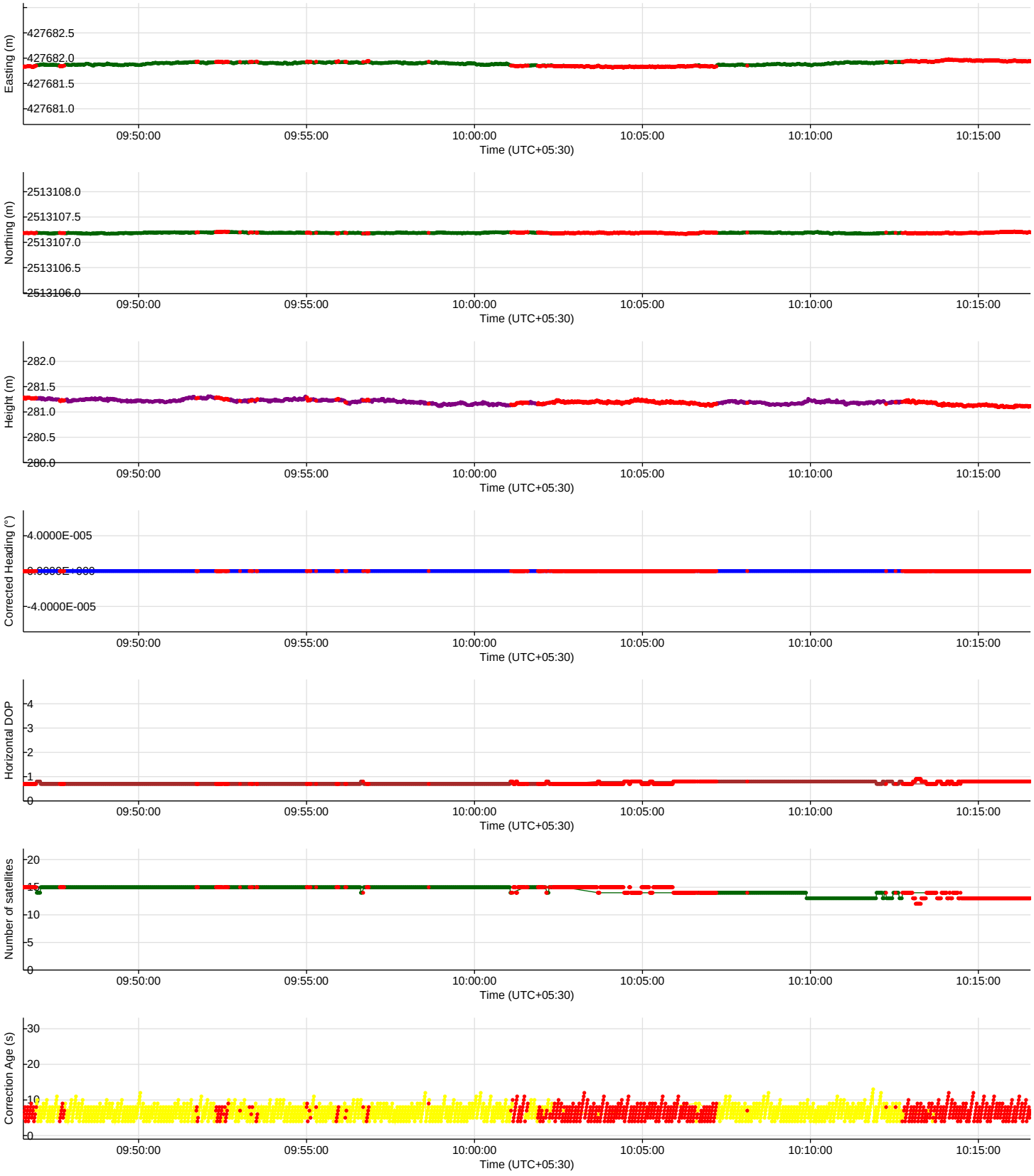
Scatter Plot



Mean Position

	Easting	Northing
Tripod	4,27,681.893m E	25,13,107.186m N

Time Series Plots for Tripod



SBES Calibration

SBES Barcheck Correction Table

Project No.	Project Title:	Vessel:	Place:
J-HYD-20-174630	**Bathymetry Survey**	**POLARIS**	**PATADUNGRI DAM**
Date:	Time:	Client:	
06-Mar-21	**11:29**	**GOV. OF GUJRAT**	
Observed By: ARPIT BOSE		Echo Sounder Model and SL. No.	Area Depth
Project No. J-HYD-20-174630		**E20 ECHOTRAC**	**9**

Echo Sounder Settings

Draft HI	Draft LO	Sound Velocity	
		Average	**Upto Depth**
0.3	**0.3**	**1494.6**	**9**
Barcheck Frequency selected	**Survey Frequency:**	Manufacturer's Accuracy	
High 200 KHz	**33 and 200 KHz**	0.10 % of Depth	0.01 m

Observations while lowering			Observations while hoisting		
Bar Depth (m)	ES Reading (m)	Difference (m)	Bar Depth (m)	ES Reading (m)	Difference (m)
1	1	0	7	7.01	-0.01
2	2	0	6	6	0
3	3	0	5	5	0
4	4	0	4	4	0
5	5	0	3	3	0
6	6	0	2	2	0
7	7	0	1	1	0

Average	0.00	Average	0.00
Std. Dev	0.0000	Std. Deviation	0.0038
		Cumulative Average	0.00
		Cumulative Std. Deviation	0.0027

Partychief	Deputy Executive Engineer
Arpit Bose	
FSINPVT	Patadungri Dam,Govt. of Gujrat

Station Name: FSL-TBM Patadungri Dam

Positioning System Verification With BX-992 Reciever and Spatial Dual						
World Geodetic System 84, UTM Projection, CM 075º East, Zone 43 North						
Sensor	**Serial No.**	**Easting mE**	**Northing mN**	**Latitude**	**Longitude**	**Ellipsoidal height (m)**
TRIMBLE BX992 RECEIVER	025-00009601	427673.600	2513098.021	22°43’25.070”N	74°17’44.475”E	274.839
Spatial Dual	025-272968	427673.369	2513097.916	22°43’25.067”N	74°17’44.467”E	274.828
	Difference	**0.231**	**0.105**	**--**	**--**	**0.011**

Location Name:	PATADUNGRI DAM	Date:	08/06/2021	Instrument Name	LYNX
Work:	RTK Observation by Topography Team			Model no.	H6

Station Name		Observation Duration	Easting (mE)	Northing (mN)	RL Height (m)	Remarks		
PATADUNGRI TBM	By rover 1	2 sec	427673.581	2513097.979	170.079	XYZ Value generated by RTK of Topography Team on Base Station TBM 03 Fugro Provided XYZ Value	Field photo\IMG_20210608_190321.jpg	Field photo\IMG_20210608_190330.jpg
PATADUNGRI TBM	By rover 2	2 sec	427673.589	2513098.003	170.075	XYZ Value generated by RTK of Topography Team on Base Station TBM 03 Fugro Provided XYZ Value	Field photo\IMG_20210608_190414.jpg	

		Fugro Provided XYZ Value								Difference With Fugro Provided XYZ Value		
Station Name	Remarks	Easting (mE)	Northing (mN)	RL Height (m)	Station Name	Remarks	Easting (mE)	Northing (mN)	RL Height (m)	Easting (mE)	Northing (mN)	RL Height (m)
PATADUNGRI TBM	Fugro Provided Value	427673.600	2513098.021	170.050	PATADUNGRI TBM	Check by Rover 1	427673.581	2513097.979	170.079	0.019	0.042	-0.029
					PATADUNGRI TBM	Check by Rover 2	427673.589	2513098.003	170.075	0.011	0.018	-0.025

Note: Client has confirmed that the TBM value(170.050m/557.90ft) is not from MSL but is from any other unknown/old reference.
Note: Base station was on Patadungri TBM 3 (Fugro provided base value), 2 reading taken for 2 sec each on PATADUNGRI TBM by 2 rovers on pole mounted.

Prepared by Arunabha Chakraborty

Appendix E

Benchmark Descriptions

(4 pages)

Fugro Survey (India) Pvt. Ltd. D-222/30, TTC Industrial Area, MIDC, Nerul, Navi Mumbai Pin - 400 075 (India)	Station / Bench Mark Description		
	Job No. :	J_HYD_20_174630	Station Name:
	Client :	Govt. Of Gujarat	
	Location :	Patadungri Dam	PATADUNGRI-TBM
	Observed By:	Arpit Bose,Mathiazhagan	
	Date:	04/03/2021	

Brief Description of the Method Adopted

1. Purpose of Establishing the station :- Ref. Station for Bathymetric Survey of Reservoir and Topography survey.
2. Equipment Deployed :- Trimble BX992 Receiver
3. Method Used :- 30 minutes Mean Position for Tripod Centre Of Gravity

Final Coordinates in WGS84 Datum/UTM zone-43N

GEOGRAPHICAL COORDINATES:		UTM COORDINATES:		CM: 75° E
LATITUDE:	22°43'25.07059"N	EASTING:	427,673.60 m	σ = +/- 0.01 m
LONGITUDE :	74°17'44.47554"E	NORTHING:	2,513,098.02 m	σ = +/- 0.01 m
ELLIPSOIDAL HEIGHT:	274.839	CONVERGENCE :	-0.50293 Degrees	
HEIGHT ABOVE LAT/CD:	NA	TBM VALUE:	170.05	

LOCATION & ACCESS : It's a square type box which is situated in Concrete Structure near HR Cabin in Patadungri Dam.

STATION MARKING : TBM establised by Govt. of Gujarat. And point is marked with red paint.

Expected durability of the Station (Years) : 10years

DETAILED DIAGRAM :

Note:-

Coordinates are measured by DGPS observation.
Client hasn't supplied any X,Y Value
Client has supplied TBM RL Value.

Client has confirmed that the TBM value(170.050m/557.90ft) is not from MSL but is from any other unknown/old reference.

Arpit Bose
Party chief (FSINPVT)

Deputy Executive Engineer
Patandungri Dam
GOVT. OF GUJRAT

FUGRO

Fugro Survey (India) Pvt. Ltd.
D-222/30, TTC Industrial Area,
MIDC, Nerul, Navi Mumbai
Pin - 400 075 (India)

Station / Bench Mark Description

Job No. :	J_HYD_20_174630	**Station Name:**
Client :	Govt. Of Gujarat	
Location :	Patadungri Dam	**PATADUNGRI-TBM**
Observed By:	Arpit Bose,Mathiazhagan	
Date:	04-03-2021	

Brief Description of the Method Adopted

1. Purpose of Establishing the station :- Ref. Station for Bathymetric Survey of Reservoir and Topography survey.
2. Equipment Deployed :- Trimble BX992 Receiver
3. Method Used :- 30 minutes Mean Position for Tripod Centre Of Gravity

Final Coordinates in WGS84 Datum/UTM zone-43N

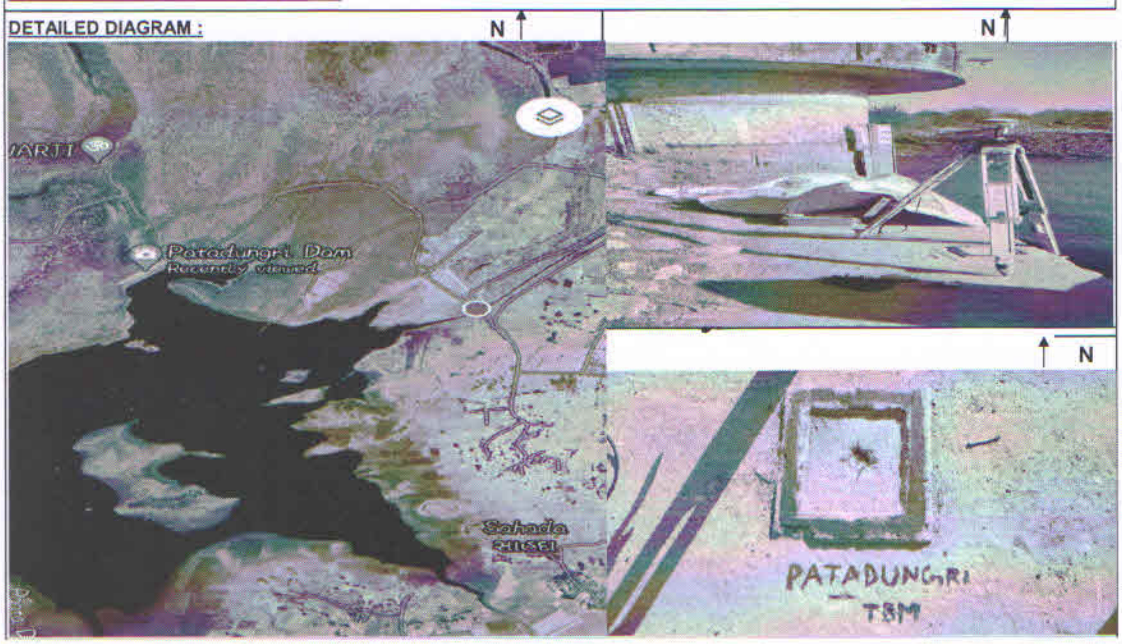
GEOGRAPHICAL COORDINATES:		UTM COORDINATES:		CM: 75° E
LATITUDE:	22°43'25.07059"N	EASTING:	4,27,673.60 m	σ = +/- 0.01 m
LONGITUDE :	74°17'44.47554"E	NORTHING:	25,13,098.02 m	σ = +/- 0.01 m
ELLIPSOIDAL HEIGHT:	274.839	CONVERGENCE :	-0.50293 Degrees	
HEIGHT ABOVE LAT/CD:	NA	TBM VALUE:	170.05	

LOCATION & ACCESS : It's a square type box which is situated in Concrete Structure near HR Cabin in Patadungri Dam.

STATION MARKING : TBM establised by Govt. of Gujarat. And point is marked with red paint.

Expected durability of the Station (Years) : 10years

DETAILED DIAGRAM :



Note:-

Coordinates are measured by DGPS observation.
Client hasn't supplied any X,Y Value
Client has supplied TBM RL Value.
Client has confirmed that the TBM value (170.050m/557.90 ft.) is not from MSL but is from any other unknown/old reference.

Arpit Bose
Party chief (FSINPVT)

25/03/21
Deputy Executive Engineer
Patandungri Dam
GOVT. OF GUJRAT

Fugro Survey (India) Pvt. Ltd. D-222/30, TTC Industrial Area, MIDC, Nerul, Navi Mumbai Pin - 400 075 (India)	**Station / Bench Mark Description**		
	Job No. :	**J_HYD_20_174630**	**Station Name:**
	Client :	**Govt. Of Gujarat**	
	Location :	Patadungri Dam	**TBM-03**
	Observed By:	Arpit Bose,Mathiazhagan	
	Date:	04/03/2021	

Brief Description of the Method Adopted

1. Purpose of Establishing the station :- Ref. Station for Bathymetric Survey of Reservoir and Topography survey.
2. Equipment Deployed :- Trimble BX992 Receiver
3. Method Used :- 30 minutes Mean Position for Tripod Centre Of Gravity

Final Coordinates in WGS84 Datum/UTM zone-43N

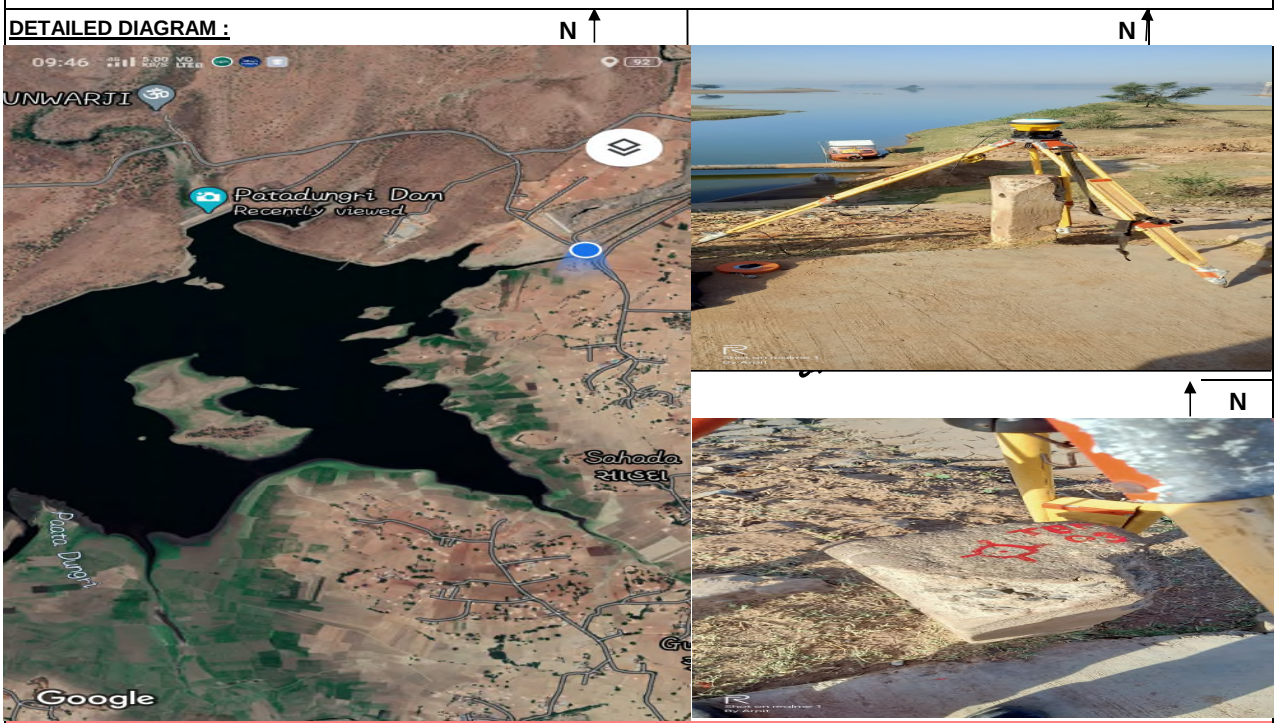
GEOGRAPHICAL COORDINATES:		**UTM COORDINATES:**		CM: 75° E
LATITUDE:	22°43'25.36992"N	EASTING:	427,681.89 m	σ = +/- 0.01 m
LONGITUDE :	74°17'44.76471"E	NORTHING:	2,513,107.19 m	σ = +/- 0.01 m
ELLIPSOIDAL HEIGHT:	280.676m	CONVERGENCE :	-0.50293 Degrees	
HEIGHT ABOVE LAT/CD:	NA	TBM VALUE:	176.026m	

LOCATION & ACCESS : It's a concrete pillar which is situated in upper stair near HR Cabin in Patadungri Dam.

STATION MARKING : TBM established by Govt. of Gujarat. And point is marked with red paint.

Expected durability of the Station (Years) : 05 years

DETAILED DIAGRAM :



Note:-

Coordinates are measured by DGPS observation.
Client hasn't supplied any X,Y Value
Client has supplied TBM RL Value.

Value has transferred from Patandungri-TBM value which has confirmed that the value is not from MSL but it is from any other unknown/old reference.

Arpit Bose
Party chief (FSINPVT)

Deputy Executive Engineer
Patandungri Dam
GOVT. OF GUJRAT

FUGRO

Fugro Survey (India) Pvt. Ltd.
D-222/30, TTC Industrial Area,
MIDC, Nerul, Navi Mumbai
Pin - 400 075 (India)

Station / Bench Mark Description

Job No. :	J_HYD_20_174630	Station Name:
Client :	Govt. Of Gujarat	
Location :	Patadungri Dam	TBM-03
Observed By:	Arpit Bose,Mathiazhagan	
Date:	04-03-2021	

Brief Description of the Method Adopted

1. Purpose of Establishing the station :- Ref. Station for Bathymetric Survey of Reservoir and Topography survey.
2. Equipment Deployed :- Trimble BX992 Receiver
3. Method Used :- 30 minutes Mean Position for Tripod Centre Of Gravity

Final Coordinates in WGS84 Datum/UTM zone-43N

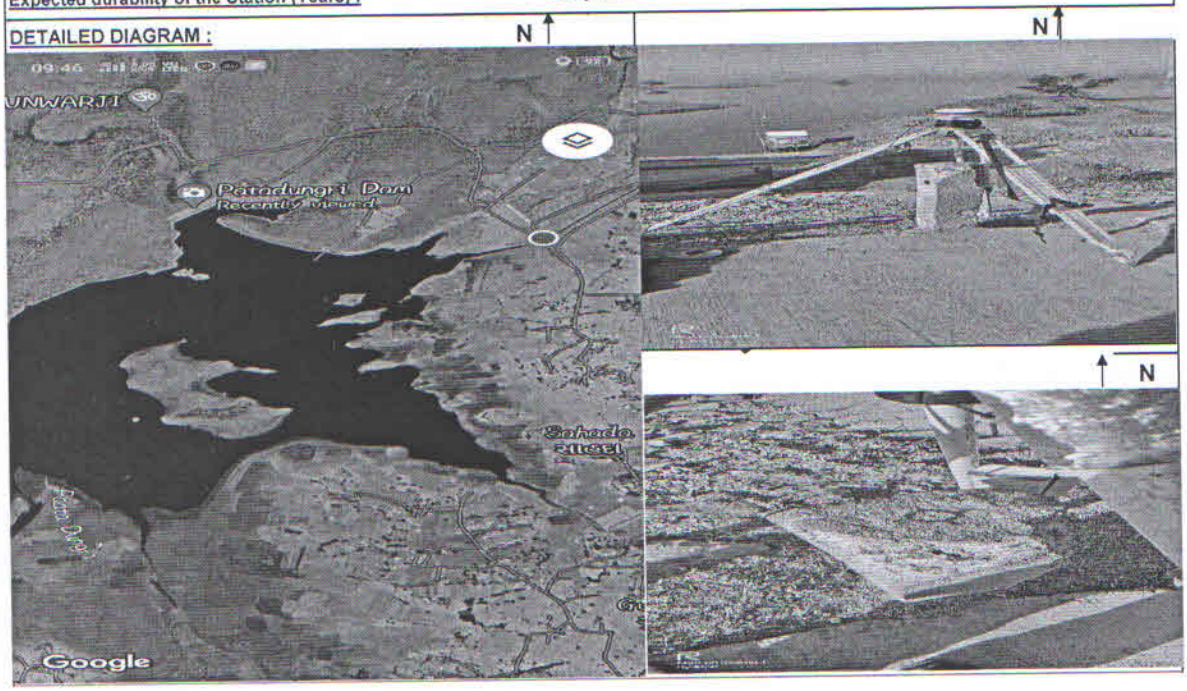
GEOGRAPHICAL COORDINATES:		UTM COORDINATES:		CM: 75° E
LATITUDE:	22°43'25.36992"N	EASTING:	4,27,681.89 m	σ = +/- 0.01 m
LONGITUDE :	74°17'44.76471"E	NORTHING:	25,13,107.19 m	σ = +/- 0.01 m
ELLIPSOIDAL HEIGHT:	280.676m	CONVERGENCE :	-0.50293 Degrees	
HEIGHT ABOVE LAT/CD:	NA	TBM VALUE:	176.026m	

LOCATION & ACCESS : It's a concrete pillar which is situated in upper stair near HR Cabin in Patadungri Dam.

STATION MARKING : TBM establised by Govt. of Gujarat. And point is marked with red paint.

Expected durability of the Station (Years) : 05 years

DETAILED DIAGRAM :



Note:-
Coordinates are measured by DGPS observation.
Client hasn't supplied any X,Y Value
Client has supplied TBM RL Value.

Value has transferred from Patandungri-TBM value which has confirmed that the value is not from MSL but it is from any other unknown/old reference.

Arpit Bose
Party chief (FSINPVT)

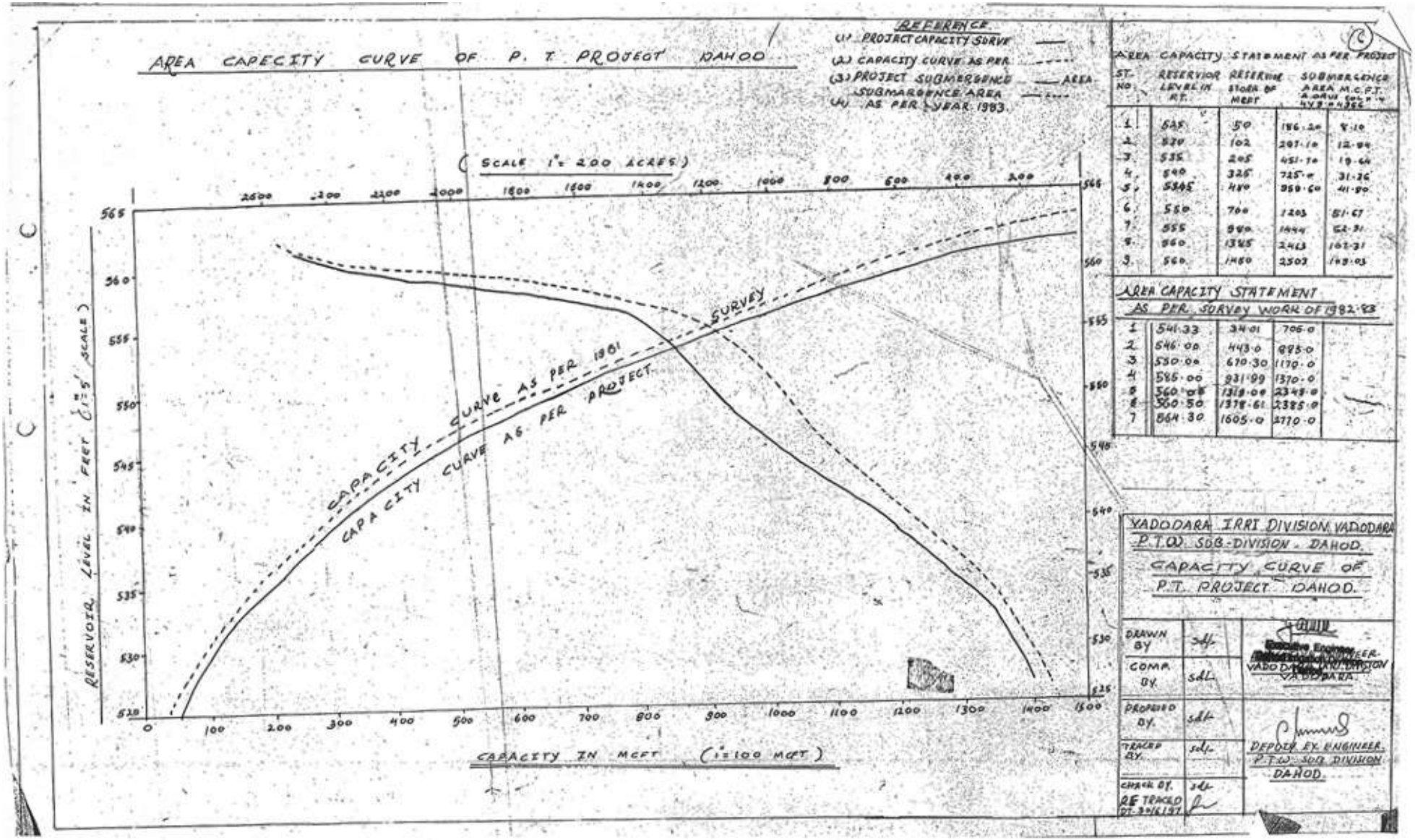
Deputy Executive Engineer
Patandungri Dam
GOVT. OF GUJRAT

Appendix F

Client Supplied Elevation-Area-Capacity Curve

(1 page)

Client Supplied Elevation-Area-Capacity Curve



Appendix G

List of Deliverables

(1 page)

List of Reports / Documents to be Submitted

Sr. No.	Type of Report / Document	Reporting Schedule	No. of Copies (Hard)	Remarks
1	Survey Procedure (QA Document)	01 December 2020	1	Submitted
2	Mobilisation Report (With Results of Calibration)	26 October 2020	--	Fugro Office copy only
4	Draft Report	30 days from completion of survey	1	Submitted
5	Final Report on Survey	1 week from receipt of client's comments	10	**This Document**

Details of Charts Accompanying this Report

Details of Charts							
Sl. No.	Charts showing	Sheet No.	Encl. No.	Dwg No.: J-HYD-20-174630/ WRD/GUJARAT/BS/	Rev. No	HS	VS
1	Reservoir Bed and Topography Heights	01 of 01	01 of 04	B/01/9512	R0/Rev.0	1:5000	-
2	Contour Map of Patadungri Reservoir	01 of 01	02 of 04	B/01/9643	R0/Rev.0	1:5000	-
3	Seabed Relief Image Prepared from SBES Data	01 of 01	03 of 04	I/01/9644	R0/Rev.0	1:5000	-
4	Patadungri Reservoir Bed Profiles (L-section and C-section)	01 of 01	04 of 04	P/01/9653	R0/Rev.0	1:5000	1: 250