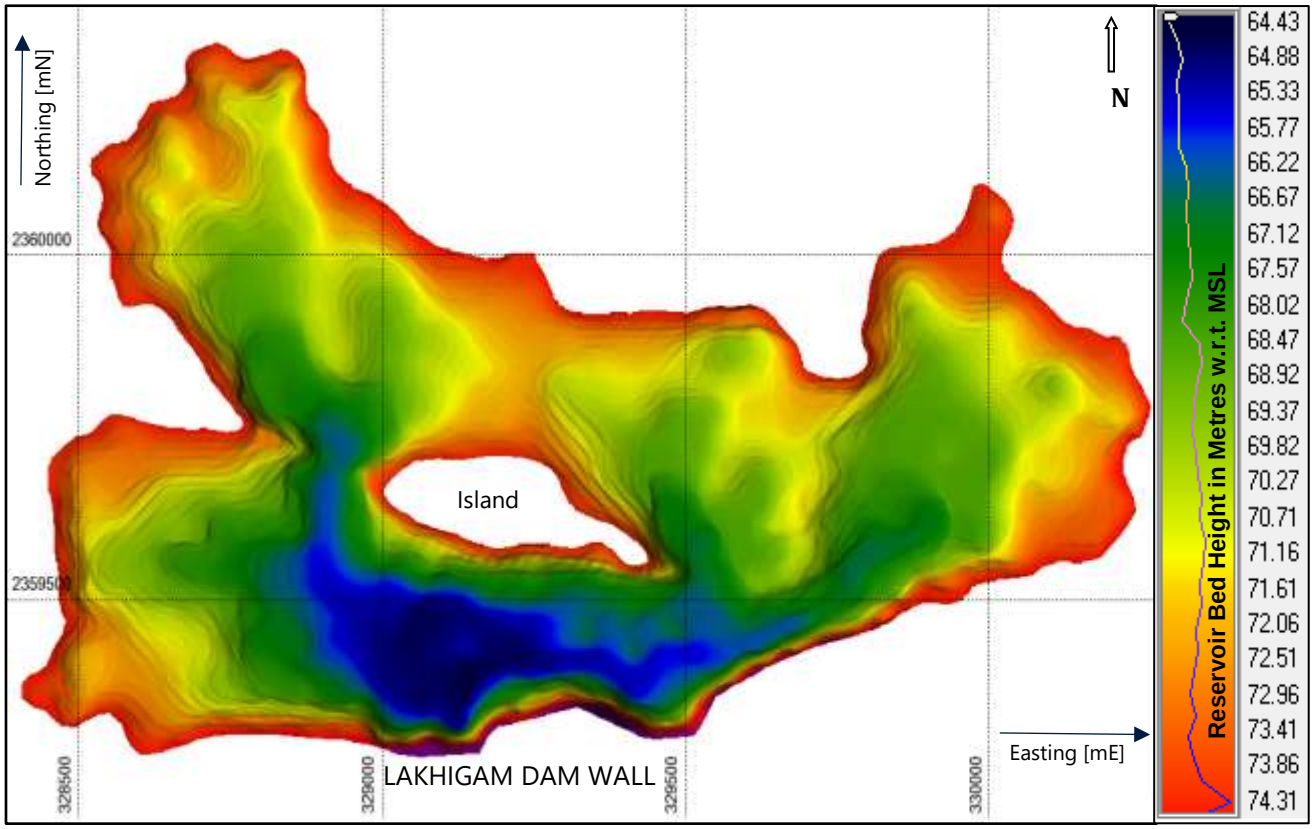


Providing Services for Conducting Bathymetric Survey of Reservoirs of Central Gujarat Under National Hydrology Project

Survey Results of Lakhigam Reservoir Location | Central Gujarat

JHYD20-174630-Volume 7-Lakhigam Reservoir/R0 [00] | 13 October 2021

Final Report

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

Narmada, Water Resources, Water Supply and Kalpsar Department
WRD (Water Resources)

Document Control

Document Information

Project Title	Providing Services for Conducting Bathymetric Survey of Reservoirs of Central Gujarat Under National Hydrology Project
Document Title	Survey Results of Lakhigam Reservoir Location
Fugro Project No.	J-HYD-20-174630
Fugro Document No.	JHYD20-174630-Volume 7-Lakhigam Reservoir/R0
Revision Number	[00]
Issue Status	Final Report

Client Information

Client	Narmada Water Resources, Water Supply and Kalpsar Department / Government of Gujarat
Client Address	Executive Engineer, W.R.I. Division, C – 9, Multistoried Building, Lal Darvaja, Ahmedabad, Gujarat - 380001
Client Contact	Mr. Piyush Bhattacharjee
Client Document No.	NOA NNo.WRIDn/SK/NOA/1588/2020 Dated 09 November 2020

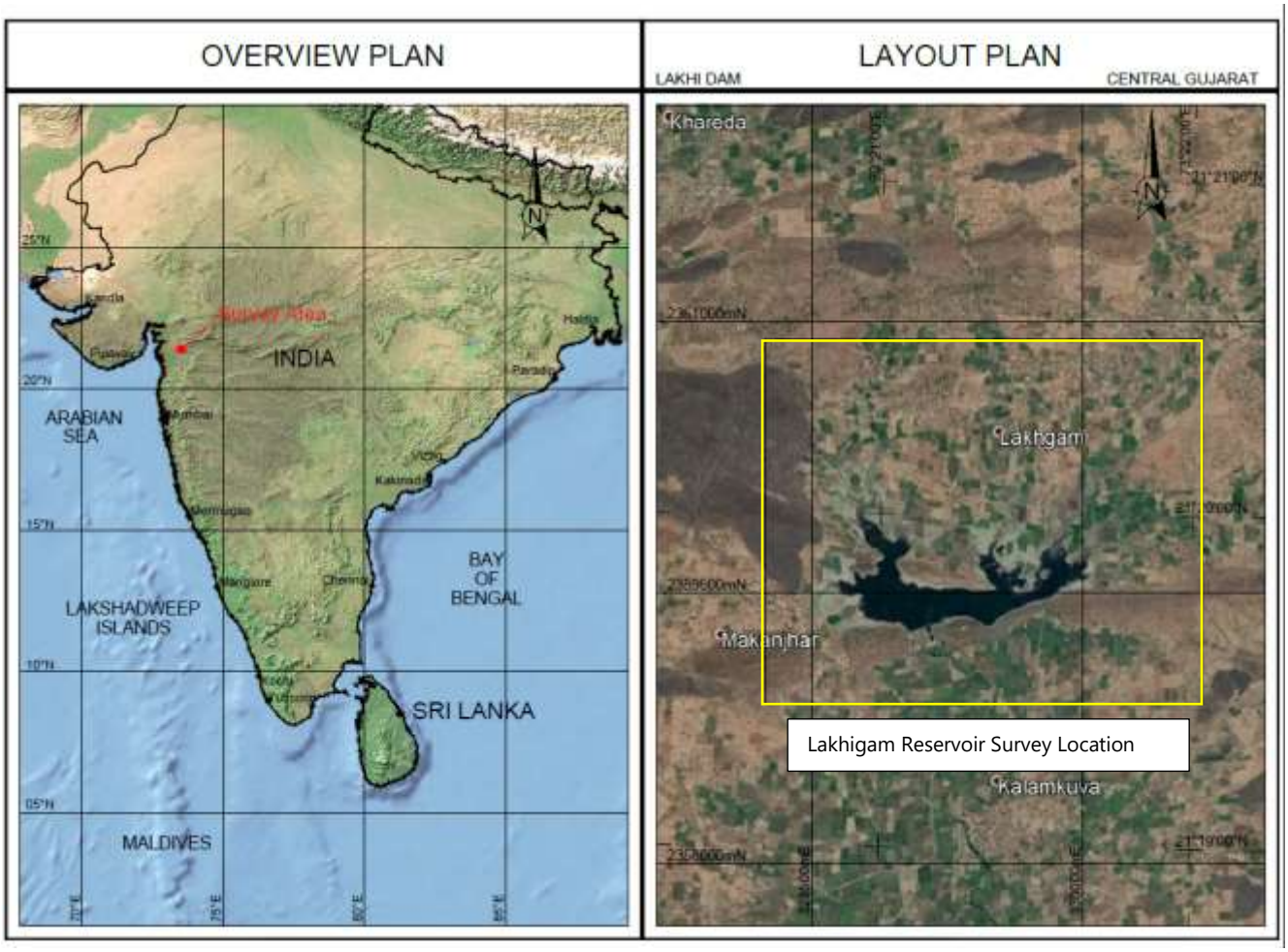
Distribution List

Revision Details	Distribution Details	Hard copy	Soft Copy
[00]	a) Narmada Water Resources, Water Supply and Kalpsar Department / Government of Gujarat	--	PDF
R0 [00]	b) FSINPVT Archive	--	PDF

Revision History

Rev	Date	Status	Prepared By	Checked By	Approved By
[00]	13 October 2021	Final Report	Alok A /Sukla C.	G.N. Hariharan	Rahul Patkar

LOCATION MAP



EXECUTIVE SUMMARY

Survey Overview– Lakhigam Reservoir Location	
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 at Lakhigam reservoir location; • Pass 1: Bathymetry / Hydrographic Survey. • Pass 2: Topographical Survey
Data Acquisition:	**FSINPVT** mobilised their bathymetry and topographical survey team and equipment along with survey boat 'Fugro Zodiac' in the months of April -May 2021 and August 2021 respectively, in order to acquire survey data as per mutually agreed scope and relevant survey specifications.
Survey Location	Lakhigam Reservoir, Lakhigam village, Mandvi Taluka, Surat District, 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.
Tidal Corrections	All raw water depths were reduced to reservoir water levels. The water level heights or reservoir water levels w.r.t. MSL were observed for the entire survey period and the same was used to calculate the reservoir bed heights w.r.t. MSL.

Survey Findings – Lakhigam 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 64.5 m (329 141 mE, 2 359 390 mN) w.r.t. MSL.
Elevation Area Capacity Curve (2021 Survey)	Elevation Area Capacity table and curve of Lakhigam 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 (64.5 m) to FRL (74.10 m) was calculated using GIS software.
Revised elevation area capacity details	In comparison with 2016 survey data, the present survey results indicate that the gross storage capacity has increased.
Loss in gross storage capacity	As per 2021 survey results, the increase in Gross storage capacity w.r.t. 2016 or volume of sediment removed/desilted in the Lakhigam reservoir is 0.385 Mm^3.
Trap efficiency & Sedimentation Index	Trap Efficiency and sedimentation Index calculated for Lakhigam reservoir as per methodology give in IS 12182-1987 is 96% and 4.819 x 10^{11} s^2/m respectively.
Sedimentation rate	The rate of siltation in Lakhigam reservoir is (-) 0.072 Mm^3/year.
Average rate of siltation	The observed rate of siltation in the Lakhigam reservoir during the 5 year life span (2016 – 2021), works out to (-) 53.682 Ha m/100 sq km/year.
Annual % loss	The annual % loss in gross storage capacity for Lakhigam reservoir w.r.t. 2016 survey i.e., in last 5 year is (-) 1.835% indicating desiltation process.

Note: The negative sign for sedimentation rate, average rate of siltation and Annual % loss indicates desiltation in reservoir

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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
FSL	Full Supply Level
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	Minimum 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 25 September 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 sediments 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) reservoir 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 at Lakhigam reservoir;

Pass 1: Bathymetry / Hydrographic Survey;

Pass 2: Topographical Survey.

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

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

1.2 Study Area

The present study area – Lakhigam reservoir falls within Tapi basin (Tapi Lower Sub-Basin). The Tapi basin has an area of 65,145 km^2 spread across the states of Maharashtra, Madhya Pradesh and Gujarat. Majority of the Tapi basin area falls in the Maharashtra state (76.73%) while the remaining area is covered in the states of Madhya Pradesh (14.2%) and Gujarat (9.07%).

The Tapi basin is sub-divided into three sub-basins: Tapi Upper Sub-Basin (29,430 km^2), Tapi Middle Sub-Basin (25,320 km^2) and Tapi Lower Sub-Basin (10,395 km^2).

The Tapi basin is formed by the Tapi river which is the second largest westward draining interstate river of the Peninsula. The total length of the Tapi River from origin to outfall into the Arabian Sea is 724 km and it receives several tributaries on both the banks. There are 14 major tributaries having a length more than 50 km. On the right bank, 4 tributaries namely the Vaki, Gomai, Arunavati and Aner join the Tapi River. On the left bank, ten important tributaries namely the Nesu, Arunavati, Buray, Panjhra, Bori, Girna, Waghur, Purna, Mona and Sipna drain into the Tapi main channel (India-WRIS, 2014).

Lakhigam dam (present survey area) was constructed over Dhakni khadi river which is a minor tributary of the Tapi River located in Mandvi taluka of the Surat district. Lakhigam reservoir has catchment area of 13.34 km^2.

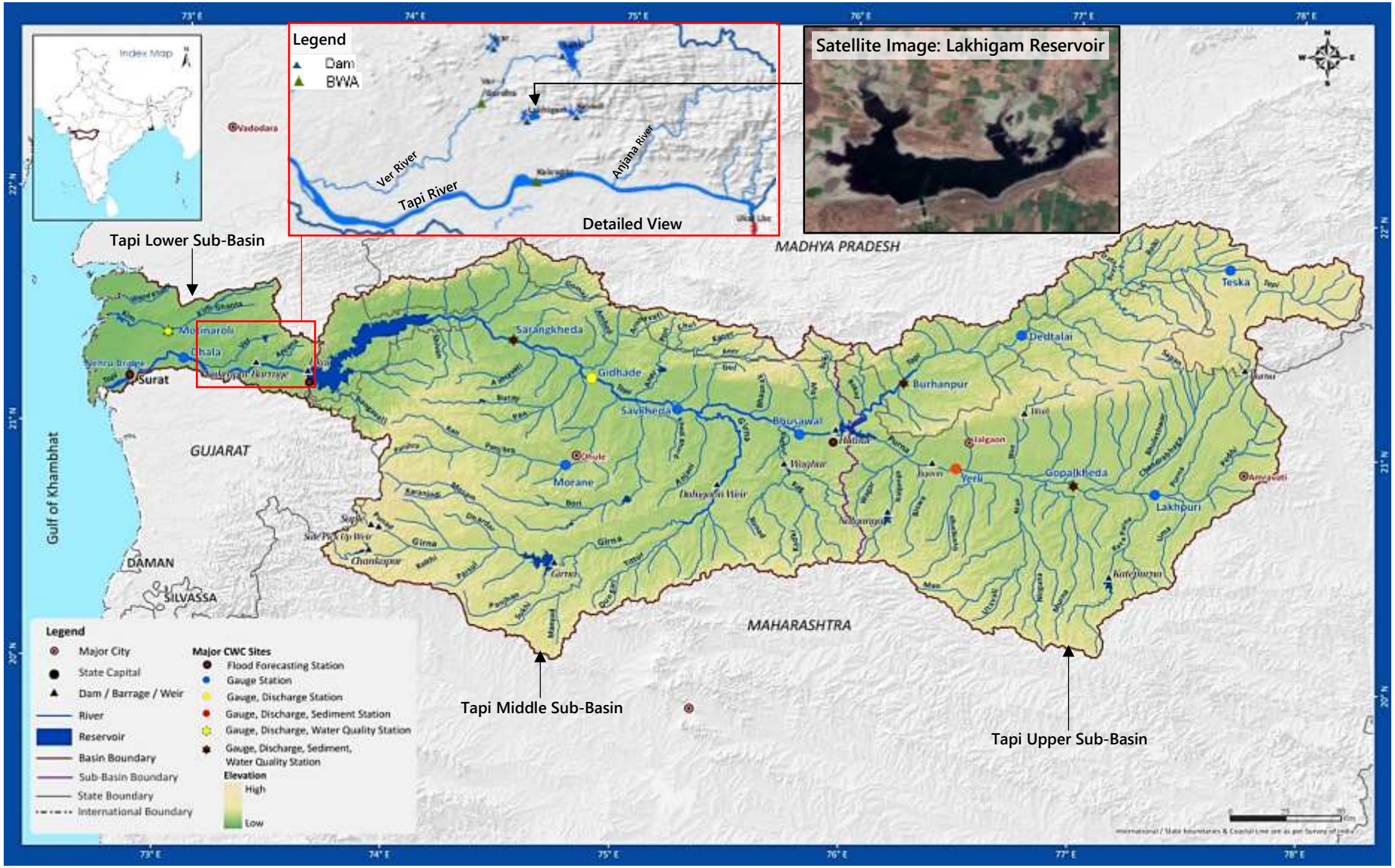

Figure 1.1: Map showing Tapi basin and its sub-basins (India-WRIS, 2014) and satellite image of Lakhigam Reservoir (Google Earth)

1.3 Geology of Study Area

Major geological formations exposed in the Surat district are Quaternary alluvium, Tertiary limestone and sandstones and Deccan Trap basalt (Ashok Kumar, 2013).

The Mandvi taluka of Surat district comprises volcanic, sedimentary and weathered rocks like Basalt, Rhyolites, Dolerite dyke, Laterite, Argillaceous limestone and clay containing nummulites and clay, friable sandstone, pebbly sandstone, a conglomerate which are remarked as fluoride - bearing minerals (Prajapati et al., 2018). Amygdaloidal basalt and dolerite dykes are encountered at the Lakhigam reservoir location in the Mandvi taluka.

1.4 Soil Types

In Surat district, four types of soils are found namely khar / khajan lands, black cotton soil, light soils and gorat soil. The Khar or Khajan types of soils are mainly found in coastal areas whereas the central part has the black alluvial and light soils. The rocky type of soil is also found in some north-eastern parts. The gorat soils are found on the banks of the rivers passing through the district. All the four soils of the district have been formed by the alluvial deposits (Directorate of Census Operations, 2011).

The Mandvi taluka has black clayey to loamy soil which is due to the presence of basaltic lava. At some places there is change in the colour of soil which is due to the presence of high iron content. Soil at piedmont sloppy area ranges from shallow-moderately deep, moderate - severely eroded and non-calcareous in nature and its texture varies from silt clay loam to clay loams (Prajapati et al., 2018).

1.5 Land use patten

Total geographical area of the Surat district is about 4 lakhs hectares. It is noteworthy to find that 76% of the geographical area is under cultivation in the district. 6 talukas out of 9 talukas have about 80% of their geographical area under cultivation. However, the coverage of forest area is only 9% (Olpad, Kamrej, Chorasi, Palasana and Bardoli taluka have no forest area). The district has only 1% area as waste land and 4% under pasture land (Directorate of Census Operations, 2011).

1.6 Lakhigam Reservoir Characteristics

The Lakhigam Dam irrigation project is constructed on the Dhakni khadi river, near Lakhigam village of Mandvi taluka in Surat district, Gujarat State. Salient features of the Lakhigam reservoir are tabulated below:

Table 1.1:Client Supplied Salient Features: Lakhigam Reservoir

Characteristics	Feature
Reservoir name	Lakhigam Reservoir
Name of Dam	Lakhigam Dam
Purpose	Irrigation
Type of Dam	Composite Earthen and Masonry Dam
Name of River	Dhakni khadi
River Basin	Tapi Lower Sub-Basin
Village	Lakhigam
Taluka	Mandvi
District	Surat
State	Gujarat
Hydrology	
Total Catchment Area	13.34 km^2
Gujarat	13.34 km^2
Maharashtra	-
Average annual rainfall	1368.30 mm
Maximum rainfall	2763.00 mm
Yield at proposed dam site @ 75% Reliability	55.43 Lac. cu. m
Routed Flood	473.70 cumecs
Design Flood Discharge	434 cumecs
Year of commencement of construction work	1979
Year of completion	1982
Dam	
Length	662.0 m
Maximum height from the deepest foundation to the top of dam	17.90 m
Maximum height from stripped level	12.40 m
Bed Rock	Amygdaloidal Basalt and Dolerite
Reservoir Details	
Gross Storage	4.895 Mm^3 (1982)
Live Storage	4.610 Mm^3 (1982)
Dead Storage	0.285 Mm^3 (1982)
Annual Utilisation	6.277 Mm^3
Net Utilisation	5.420 Mm^3
Carry over	Nil
Gross Area under submergence at F.R.L.	139.00 Ha.
Crest Level of Spillway	74.10 m
Full Reservoir Level	74.10 m

Characteristics	Feature	
Top of Dam	77.10 m	
Spillway		
Type	Ogee shaped	
Location	In river gorge	
Maximum head over spillway crest	2.50 m	
Length of the spillway	25. 00 m	
Number and type of gates	Ungated	
Canals	Right Bank	Left Bank
Capacity	-	4.93 cumecs
Length	2.1 km	6.2 km
Culturable command area	321 Ha.	400 Ha.
Type	Unlined	

1.7 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 Lakhigam reservoir.

Table 1.2: Lakhigam Reservoir details for Bathymetry and Topography Survey

Name of Dam / Reservoir	Actual Area (km^2) surveyed	
	Bathymetry Survey	Topography Survey
Lakhigam	0.22	0.88

1.8 Scope of Work

To achieve the above objective, Fugro carried out survey for eleven (11) reservoir areas in two (02) passes. The scope of work undertaken for Lakhigam reservoir is as follows:

1.8.1 Pass 1: Bathymetry / Hydrographic Survey

The scope of work conforms bathymetry survey was completed for total area of 0.22 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 Lakhigam 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 single beam echosounder system along with associated Navigational system were deployed on all the survey lines.

1.8.2 Pass 2: Topographical Survey

Topographical survey was carried out using Total station and equivalent levelling instruments. The total area of 0.88 km^2 was covered in the topographical survey. 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 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 upto 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).

1.9 Survey Execution

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

1.10 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

1.11 Deliverables

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

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. MSL 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 Lakhigam Reservoir

Date	Observed Reservoir Water Level Heights w.r.t. MSL at Lakhigam Reservoir [m]
30-04-2021	68.79
01-05-2021	68.65

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 'Fugro Zodiac'

Bathymetry Survey Personnel	
Personnel Name	**Function**
Pritam Seth	Party Chief / Surveyor
Atul Bhoyte	Engineer
MD Salman Khan	Fugro Zodiac 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	
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 Fugro Zodiac is placed at Appendix C to this document.

Table 2.6: Survey Equipment / Systems Deployed for Bathymetry Survey in Fugro Zodiac

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
Sound Velocity	Odom DigiBar Pro
Single beam Echosounder	Echotrac CV100 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 CHC I 80 System along with accessories and consumables.

2.7 Survey Vessel

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

Figure 2.1: Survey boat Fugro Zodiac

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 FRL/FSL RL height – 74.10 m w.r.t. MSL
- Full Reservoir Level (FRL) – 74.10 m w.r.t. MSL
- Water line – 68.65 m approximately.

3. Survey Data Acquisition

3.1 Survey planning, Preparation & Transportation to Site

The bathymetry survey equipment and personnel with survey boat 'Fugro Zodiac' arrived at Lakhigam reservoir location on 26 April 2021 and equipment was mobilised on-board the survey boat on 27 -29 April 2021.

After field testing / verification / calibration of all survey equipment bathymetry survey was carried out and completed on 1 May 2021. Refer Appendix A to this document for diary of events.

The topography survey equipment and personnel arrived at Lakhigam reservoir location and commenced and completed survey on 8 August 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 'Fugro Zodiac' 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 – DGNSS

The Positioning System on board 'Fugro Zodiac' was Spatial Dual. Position observations were done at Lakhigam reservoir benchmark locations, using Trimble BX-992 and Spatial Dual receiver. 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 at TBM1

Positioning System Verification Results With BX-992 and Spatial Dual Receiver (TBM1)						
World Geodetic System 84, UTM Projection, CM 075° East, Zone 43 North						
Sensor	Serial No.	Easting [mE]	Northing [mN]	Latitude	Longitude	Ellipsoidal Height [m]
Trimble BX-992	025-00009601	329114.62	2,359,292.46	21°19'39.16142"N	073°21'08.25191"E	19.282
Spatial Dual	025-00006405	329114.631	2359292.484	21°19'39.16225"N	073°21'08.25225"E	19.332
Difference		-0.010	-0.025	--	--	-0.05

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 CV100 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

Summary of SBES Calibration Results on-board 'Fugro Zodiac'			
Date	SBES Sensor [Type]	Average (m)	Standard Deviation
30 April 2021	Echotrac CV100 SBES	0.00	0.0010

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 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 Control of Work

3.5.1 RTK Verification

The RTK system verification was carried out by 'Static Observations' for 30 minutes at Temporary Benchmark 1(LAKHI DAM TBM1) and Temporary Benchmark 2 (LAKHI DAM TBM2) locations.

3.5.2 RTK Position Comparison

The RTK observed position at Temporary Benchmark location (LAKHI DAM TBM2) 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)
LAKHI DAM TBM2 (WGS 84, UTM Projection, CM 075°E, Zone 43N)			
Trimble BX-992	025-00009601	329084.111	2359283.740
RTK Rover 1	CHC I 80	329083.998	2359283.723
Difference		0.113	0.017
LAKHI DAM TBM2 (WGS 84, UTM Projection, CM 075°E, Zone 43N)			
Trimble BX-992	025-00009601	329084.111	2359283.740
RTK Rover 2	CHC I 80	329084.001	2359283.714
Difference		0.110	0.026
LAKHI DAM TBM2 (WGS 84, UTM Projection, CM 075°E, Zone 43N)			
Trimble BX-992	025-00009601	329084.111	2359283.740
RTK Rover 3	CHC I 80	329084.005	2359283.707
Difference		0.106	0.033

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 Reservoir Level (FRL)- 74.1 m has been carried out by topography survey method.

The topography survey was carried out using GNSS RTK CHC I 80 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 (LAKHI DAM TBM1) 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 LAKHI DAM TBM2 location. Static observation was carried out subsequently as part of verification.
- The Base receiver is installed at LAKHI DAM TBM1 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 LAKHI DAM TBM2.
- The details of level transfer carried out by Fugro from client supplied FSL to top of dam and from top of dam to TBM1 and TBM2 is placed in Appendix E.
- 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: Temporary Benchmark 1 (LAKHI DAM TBM1)

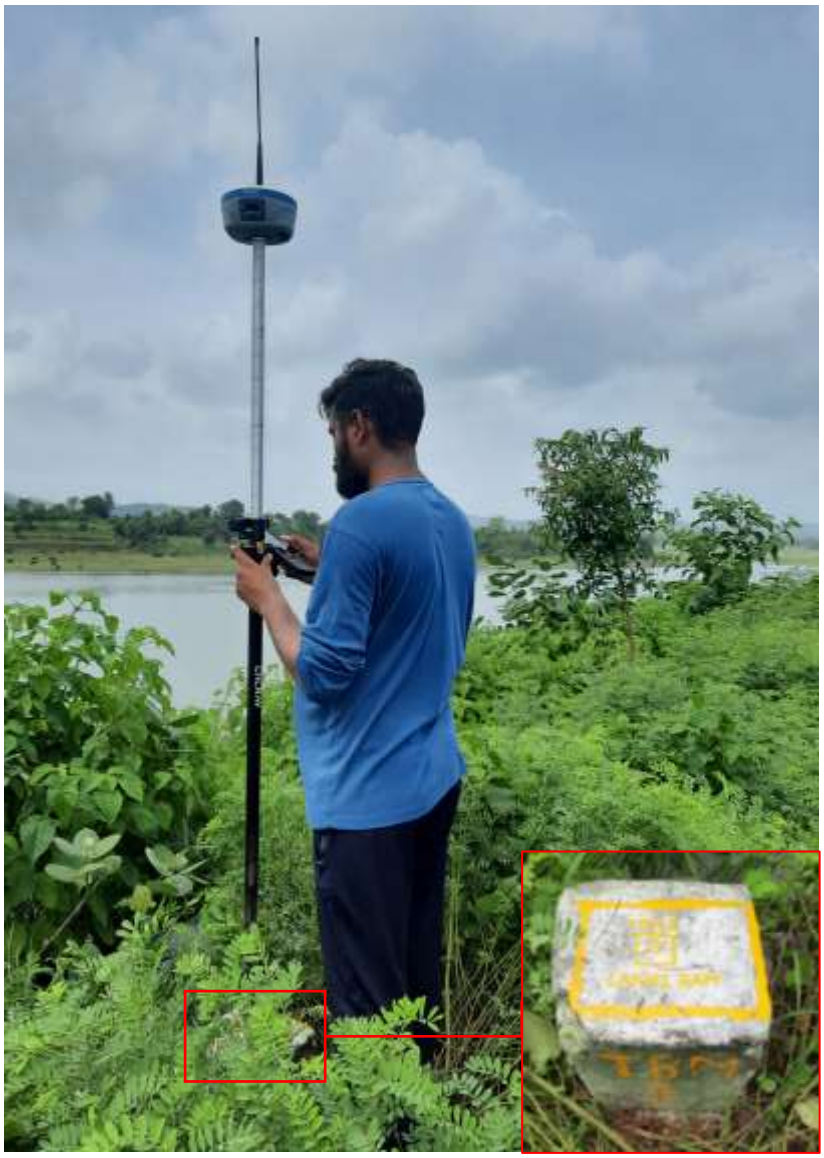

Figure 3.2: Temporary Benchmark 2 (LAKHI DAM TBM2)

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 Reservoir Level (FRL)- 74.10 m, 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 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.

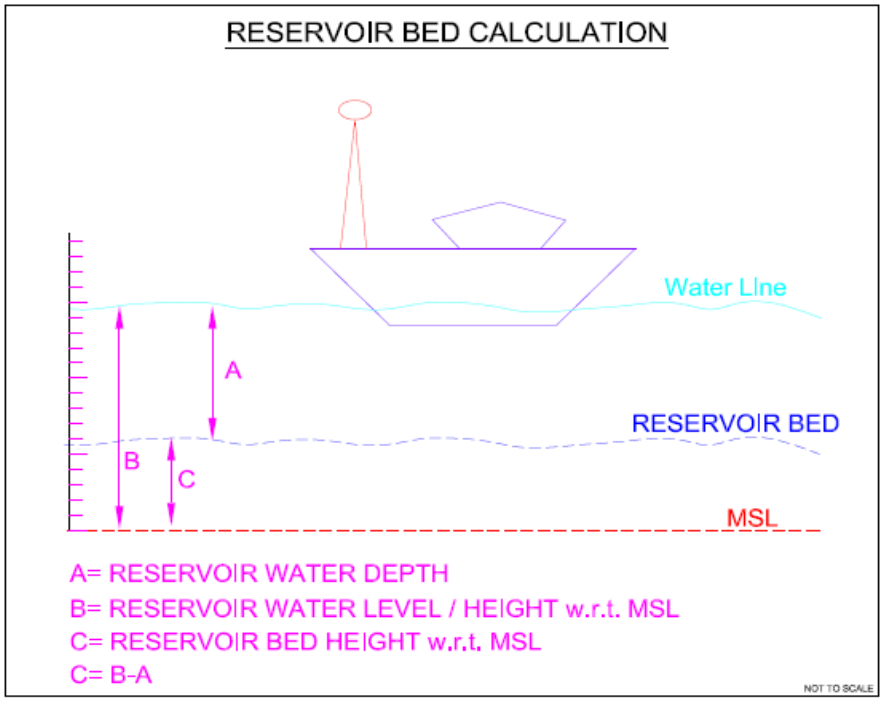

Figure 4.1: Reservoir Bed Height Calculation w.r.t. MSL

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 boundary 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 64.50 m which is the lowest bed level for the reservoir and the maximum level considered is 74.10 m which is Full Reservoir Level (FRL) 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 MWL. 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.

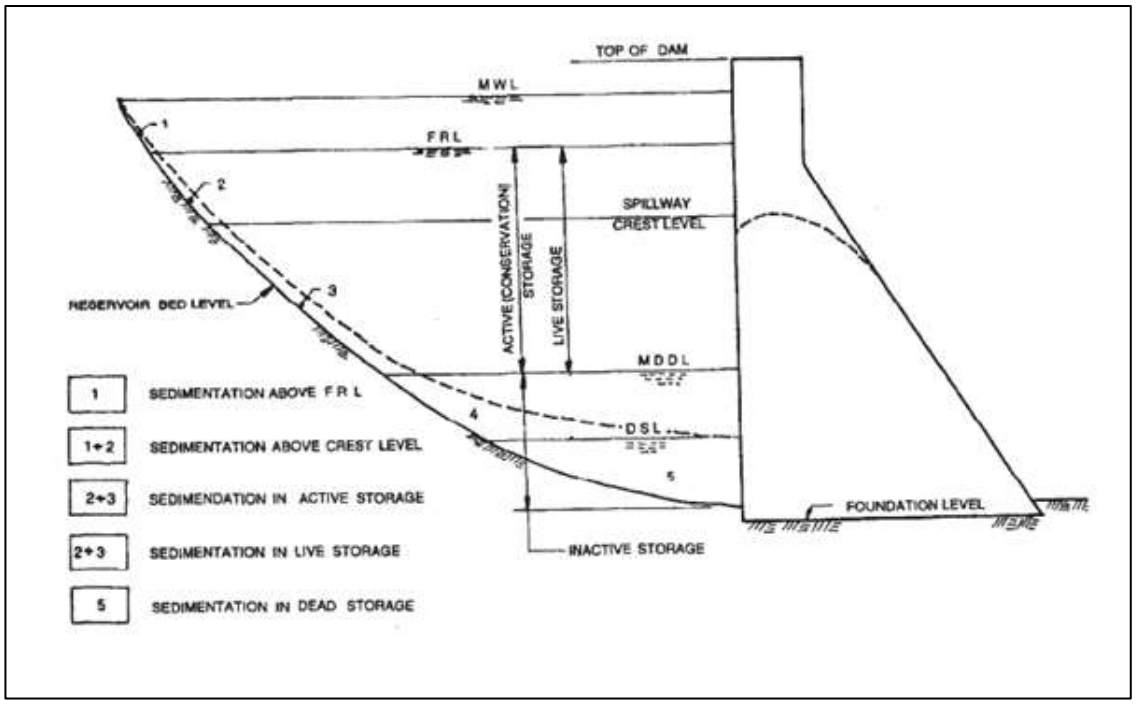

Figure 4.2: Sedimentation in different zones of reservoir (Ref: IS 5477-Part 1,1999)

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 FSL is 4.260 Mm^3 and client supplied Mean Annual inflow is 5.543 Mm^3. The values of trap efficiency were 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 for Lakhigam reservoir are shown in Table 5.4.

At last, sedimentation volumes are compared with sedimentation volumes from previous year surveys (if available) and rate of sedimentation, loss of capacity as well as annual loss percentage is computed and compared with the values of previous years (if available) 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)

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

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

4.6 Charting the Results of Bathymetry and Topography Data

- Chart showing reservoir bed heights are provided for the current survey at 1:2000 scale.
- Chart showing contour map at 1 m interval for Lakhigam reservoir is also provided at 1:2000 scale.
- Chart showing reservoir bed relief image prepared from bathymetry and topography survey data is provided at 1:2000 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 F.

5. Survey Results – Lakhigam Reservoir

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

Data acquisition for Lakhigam reservoir was carried out up to Full Supply Level (FSL)/Full Reservoir Level (FRL) of 74.10 m.

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 64.5 m to 74.1 m w.r.t. MSL.

The reservoir bed tends to get shallower as we go further towards north, east & west directions away from the reservoir dam wall within the survey area. Reservoir area is spreading towards east, west and south directions. One island is observed at the centre of the reservoir area.

Lowest reservoir bed level recorded was 64.5 m (329 141 mE, 2 359 390 mN) w.r.t. MSL, within the survey area.

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

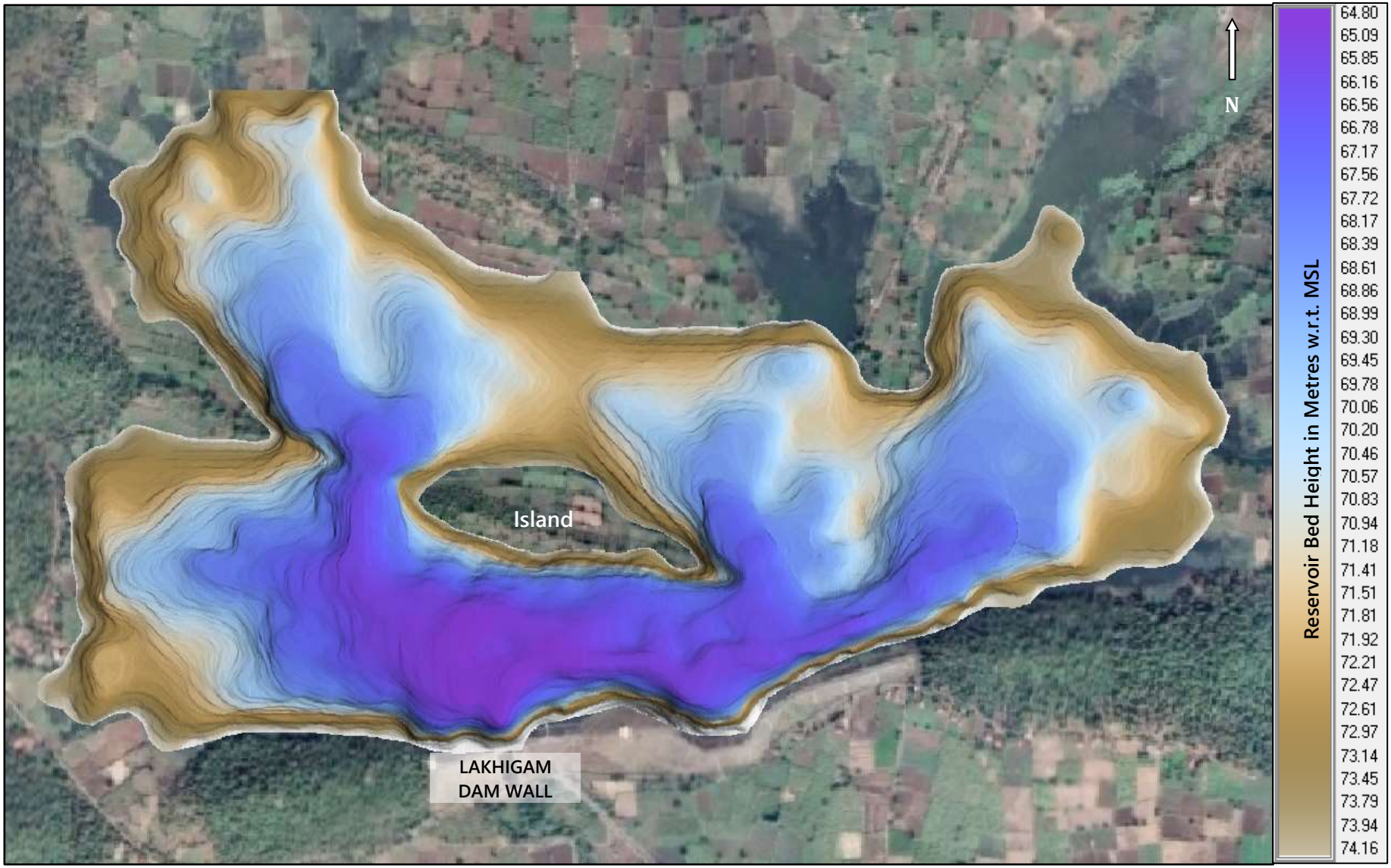

Figure 5.1: Image showing gridded SBES Bathymetry and topography data (superimposed with satellite imagery) of reservoir bed heights in metres from lowest bed level to FRL

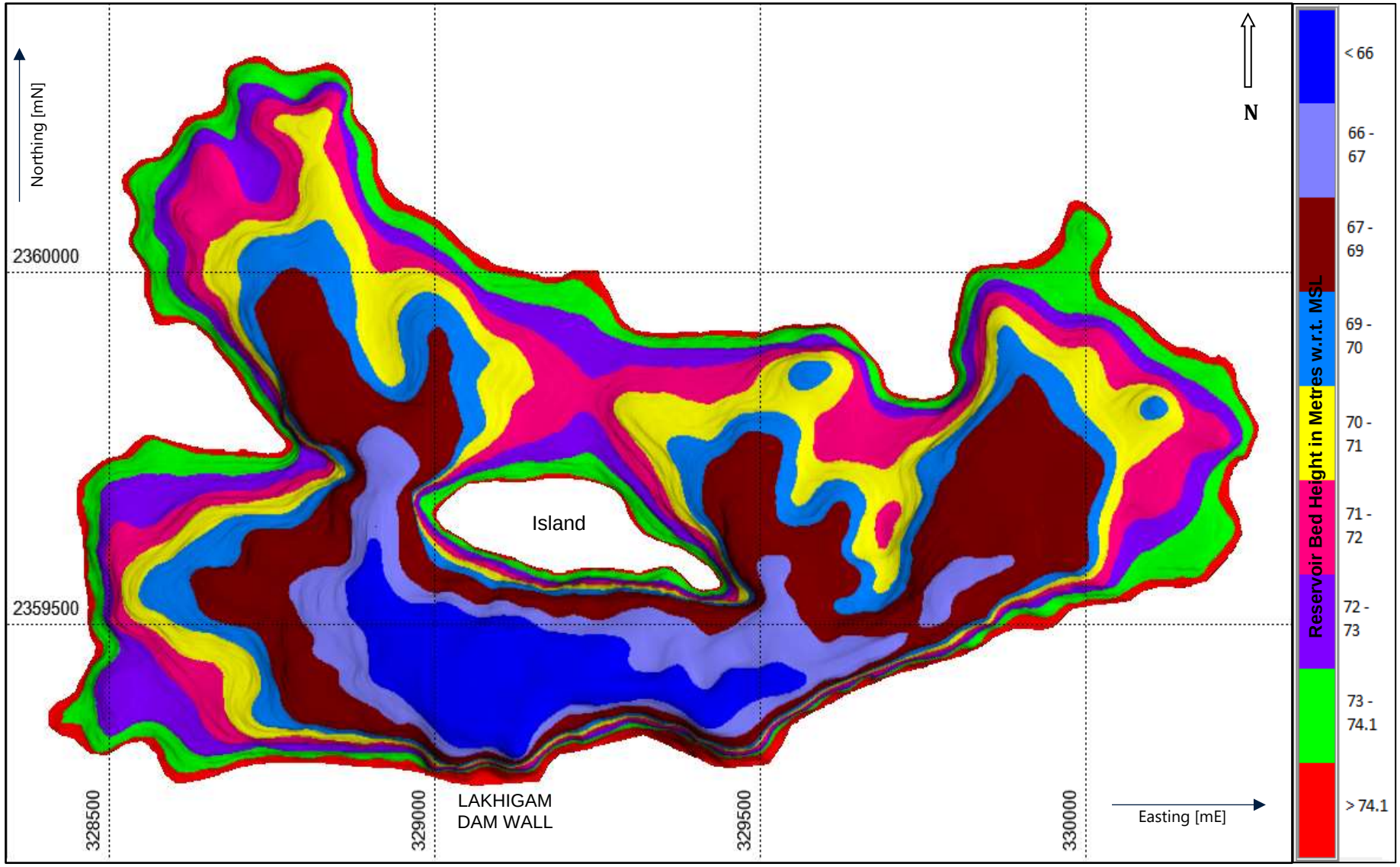

Figure 5.2: Shaded Relief Image showing gridded SBES Bathymetry and topography data of reservoir bed heights in metres from lowest bed level to FRL.

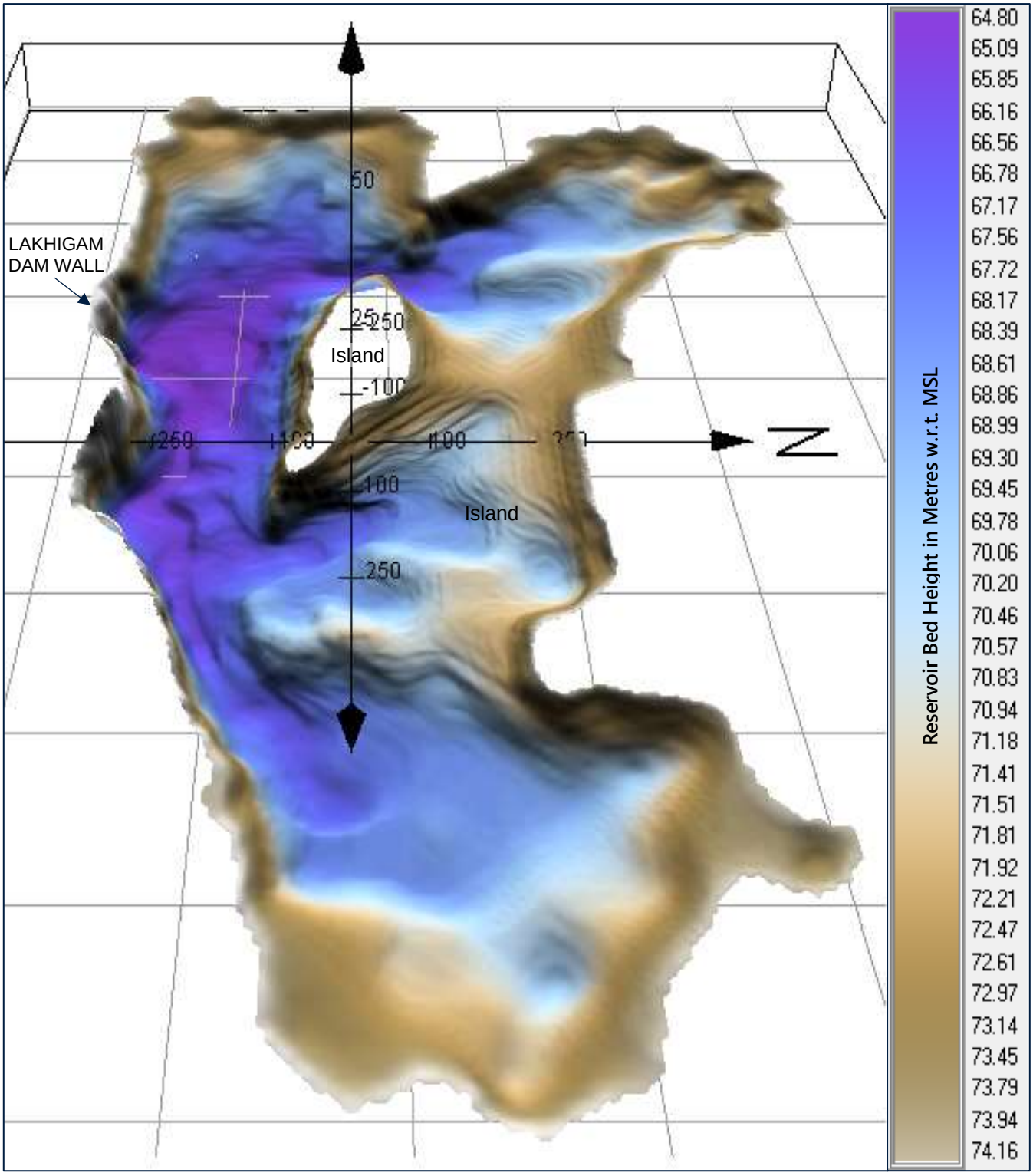

Figure 5.3: 3D view of Lakhigam Reservoir

Photograph A: Islands and areas of shallow water depth in the Western part of Lakhigam Reservoir (328806 mE, 2359887 mN)

Photograph B: South-westernmost approachable part of Lakhigam Reservoir (328634 mE, 2359464 mN) with shallow water depth.

Photograph C: View of the Western part of Lakhigam Reservoir (328716 mE, 2359612 mN) from the Lakhigam dam wall

Photograph D: Island and areas of shallow water depth in the Eastern part of Lakhigam Reservoir (329657 mE, 2359761 mN)

Figure 5.4: Photographs A, B, C and D showing in the western, south-western, eastern parts of the Lakhigam Reservoir.

5.2 Elevation Area Capacity Curve (2021)

The area and capacity of the Lakhigam reservoir was tabulated against the respective increasing elevation starting from lowest bed elevation (i.e., 64.50 m) up to 74.50 m at an increment of 0.1 m as shown in Table 5.1. Area capacity curve for Lakhigam reservoir is shown in Figure 5.5.

Table 5.1: Elevation Area Capacity table at every 0.1 m interval starting from lowest bed level to FRL for the Survey Year 2021

Elevation Area Capacity Table (2021): Lakhigam Reservoir				
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mm^3]	Remarks
1	64.50	0.0008	0.0000	Bed level
2	64.60	0.0023	0.0002	-
3	64.70	0.0119	0.0008	-
4	64.80	0.019	0.002	-
5	64.90	0.026	0.005	-
6	65.00	0.031	0.007	-
7	65.10	0.035	0.011	-
8	65.20	0.040	0.015	-
9	65.30	0.045	0.019	-
10	65.40	0.050	0.024	-
11	65.50	0.054	0.029	-
12	65.60	0.059	0.034	-
13	65.70	0.064	0.041	-
14	65.80	0.069	0.047	-
15	65.90	0.074	0.054	-
16	66.00	0.078	0.062	-
17	66.10	0.084	0.070	-
18	66.20	0.092	0.079	-
19	66.30	0.101	0.088	-
20	66.40	0.111	0.099	-
21	66.50	0.119	0.111	-
22	66.60	0.128	0.123	-
23	66.70	0.136	0.136	-
24	66.80	0.144	0.150	-
25	66.90	0.152	0.165	-
26	67.00	0.162	0.181	-
27	67.10	0.171	0.197	MDDL
28	67.20	0.181	0.215	-
29	67.30	0.190	0.233	-
30	67.40	0.199	0.253	-
31	67.50	0.208	0.273	-
32	67.60	0.218	0.294	-
33	67.70	0.229	0.317	-

Elevation Area Capacity Table (2021): Lakhigam Reservoir				
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mm^3]	Remarks
34	67.80	0.240	0.340	-
35	67.90	0.250	0.365	-
36	68.00	0.257	0.390	-
37	68.10	0.264	0.416	-
38	68.20	0.271	0.443	-
39	68.30	0.278	0.470	-
40	68.40	0.286	0.498	-
41	68.50	0.294	0.527	-
42	68.60	0.317	0.558	-
43	68.70	0.334	0.590	-
44	68.80	0.349	0.625	-
45	68.90	0.363	0.660	-
46	69.00	0.375	0.697	-
47	69.10	0.386	0.735	-
48	69.20	0.397	0.774	-
49	69.30	0.408	0.814	-
50	69.40	0.418	0.856	-
51	69.50	0.430	0.898	-
52	69.60	0.440	0.942	-
53	69.70	0.451	0.986	-
54	69.80	0.463	1.032	-
55	69.90	0.475	1.079	-
56	70.00	0.487	1.127	-
57	70.10	0.499	1.176	-
58	70.20	0.513	1.227	-
59	70.30	0.527	1.279	-
60	70.40	0.541	1.332	-
61	70.50	0.556	1.387	-
62	70.60	0.571	1.443	-
63	70.70	0.586	1.501	-
64	70.80	0.599	1.560	-
65	70.90	0.614	1.621	-
66	71.00	0.629	1.683	-

Elevation Area Capacity Table (2021): Lakhigam Reservoir				
Sr. No.	Elevation [m]	Area [km^2]	Capacity [Mm^3]	Remarks
67	71.10	0.645	1.747	-
68	71.20	0.661	1.812	-
69	71.30	0.677	1.879	-
70	71.40	0.691	1.947	-
71	71.50	0.705	2.017	-
72	71.60	0.719	2.088	-
73	71.70	0.731	2.161	-
74	71.80	0.743	2.235	-
75	71.90	0.756	2.310	-
76	72.00	0.771	2.386	-
77	72.10	0.784	2.464	-
78	72.20	0.796	2.543	-
79	72.30	0.809	2.623	-
80	72.40	0.822	2.705	-
81	72.50	0.834	2.787	-
82	72.60	0.846	2.871	-
83	72.70	0.858	2.957	-
84	72.80	0.869	3.043	-
85	72.90	0.879	3.130	-
86	73.00	0.889	3.219	-
87	73.10	0.899	3.308	-
88	73.20	0.908	3.398	-
89	73.30	0.918	3.490	-
90	73.40	0.930	3.582	-
91	73.50	0.941	3.676	-
92	73.60	0.952	3.770	-
93	73.70	0.962	3.866	-
94	73.80	0.972	3.963	-
95	73.90	0.983	4.061	-
96	74.00	0.996	4.160	-
97	74.10	1.009	4.260	FRL
98	74.20	1.022	4.361	-
99	74.30	1.036	4.464	-
100	74.40	1.048	4.568	-
101	74.50	1.055	4.674	-

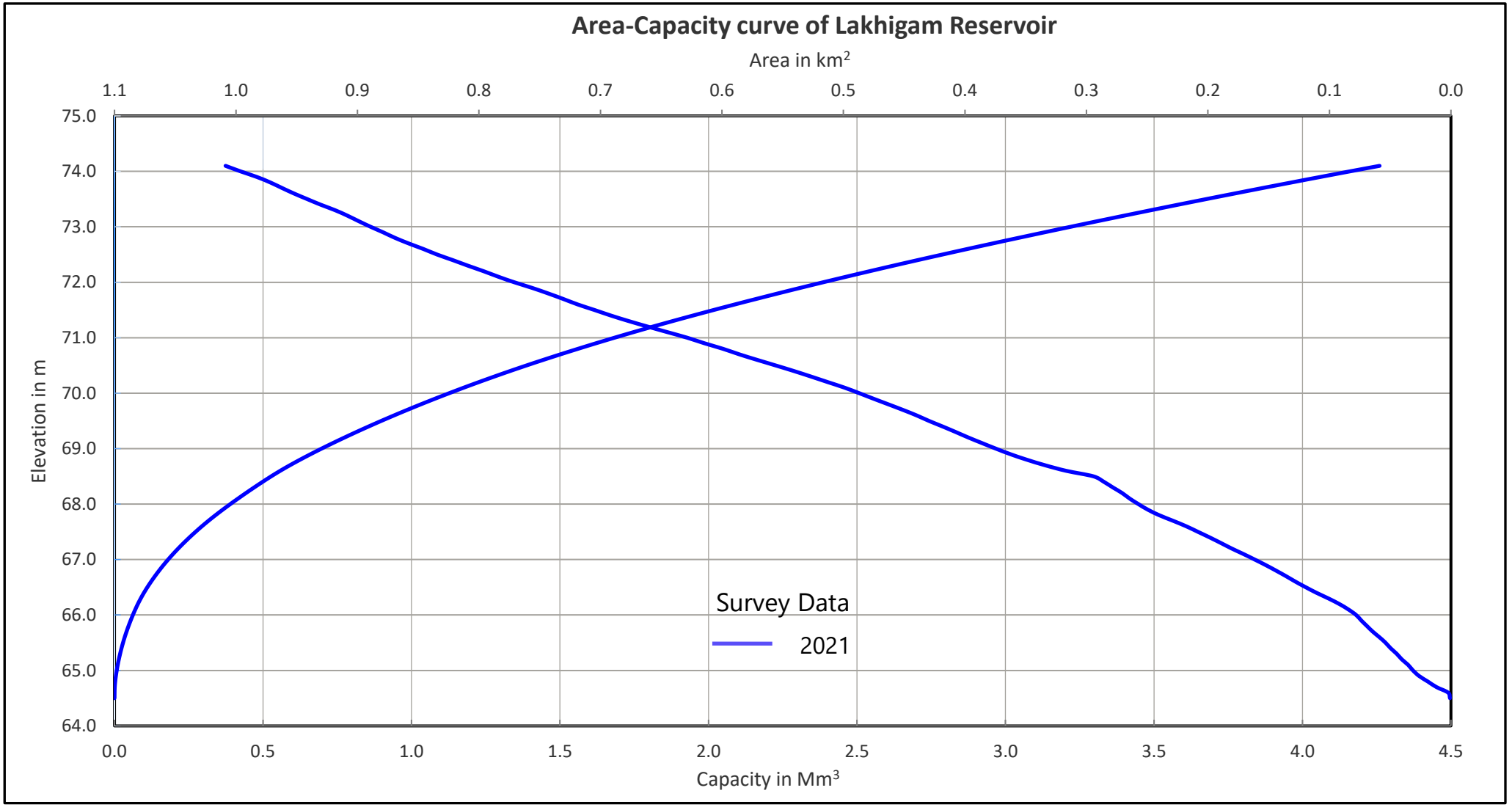

Figure 5.5: Area capacity curve for 2021 survey for Lakhigam Reservoir

5.3 Comparison of Elevation Area Capacity Details

Comparison of the elevation area capacity details for the year 2021 with the elevation area capacity details for the previou year of 2016 is shown in Table 5.2. In addition, the comparison plots of capacity curve for the years 2021 and 2016 are shown in Figure 5.6.

In general, the 2021 survey results indicate that there is an increase in the gross storage capacity w.r.t. 2016 gross storage capacity.

Table 5.2: Comparison of Elevation Area Capacity details of 2016 and 2021 survey data

Sr. No	Elevation (w.r.t. MSL) [m]	2016 Survey		2021 Survey	
		Area [km^2]	Gross Capacity [Mm^3]	Area [km^2]	Gross Capacity [Mm^3]
1	64.50	-	-	0.0008	0.0000
2	64.60	-	-	0.0023	0.0002
3	64.70	-	-	0.012	0.001
4	64.80	-	-	0.019	0.002
5	64.90	-	-	0.026	0.005
6	65.00	0.015	0.001	0.031	0.007
7	65.10	0.018	0.003	0.035	0.011
8	65.20	0.022	0.005	0.040	0.015
9	65.30	0.025	0.008	0.045	0.019
10	65.40	0.029	0.011	0.050	0.024
11	65.50	0.032	0.014	0.054	0.029
12	65.60	0.036	0.018	0.059	0.034
13	65.70	0.039	0.022	0.064	0.041
14	65.80	0.043	0.026	0.069	0.047
15	65.90	0.047	0.031	0.074	0.054
16	66.00	0.051	0.036	0.078	0.062
17	66.10	0.057	0.042	0.084	0.070
18	66.20	0.063	0.048	0.092	0.079
19	66.30	0.069	0.055	0.101	0.088
20	66.40	0.075	0.062	0.111	0.099
21	66.50	0.081	0.070	0.119	0.111
22	66.60	0.087	0.079	0.128	0.123
23	66.70	0.093	0.088	0.136	0.136
24	66.80	0.099	0.098	0.144	0.150
25	66.90	0.105	0.109	0.152	0.165

Sr. No	Elevation (w.r.t. MSL) [m]	2016 Survey		2021 Survey	
		Area [km^2]	Gross Capacity [Mm^3]	Area [km^2]	Gross Capacity [Mm^3]
26	67.00	0.110	0.120	0.162	0.181
27	67.10	0.115	0.131	0.171	0.197
28	67.20	0.120	0.143	0.181	0.215
29	67.30	0.125	0.156	0.190	0.233
30	67.40	0.130	0.169	0.199	0.253
31	67.50	0.134	0.182	0.208	0.273
32	67.60	0.139	0.196	0.218	0.294
33	67.70	0.144	0.210	0.229	0.317
34	67.80	0.149	0.225	0.240	0.340
35	67.90	0.154	0.241	0.250	0.365
36	68.00	0.161	0.257	0.257	0.390
37	68.10	0.169	0.274	0.264	0.416
38	68.20	0.178	0.291	0.271	0.443
39	68.30	0.186	0.310	0.278	0.470
40	68.40	0.195	0.329	0.286	0.498
41	68.50	0.203	0.350	0.294	0.527
42	68.60	0.211	0.371	0.317	0.558
43	68.70	0.220	0.393	0.334	0.590
44	68.80	0.228	0.416	0.349	0.625
45	68.90	0.237	0.439	0.363	0.660
46	69.00	0.246	0.464	0.375	0.697
47	69.10	0.256	0.490	0.386	0.735
48	69.20	0.265	0.516	0.397	0.774
49	69.30	0.275	0.544	0.408	0.814
50	69.40	0.284	0.572	0.418	0.856
51	69.50	0.294	0.601	0.430	0.898
52	69.60	0.303	0.632	0.440	0.942
53	69.70	0.313	0.663	0.451	0.986
54	69.80	0.323	0.695	0.463	1.032
55	69.90	0.332	0.728	0.475	1.079
56	70.00	0.346	0.763	0.487	1.127
57	70.10	0.363	0.799	0.499	1.176

Sr. No	Elevation (w.r.t. MSL) [m]	2016 Survey		2021 Survey	
		Area [km^2]	Gross Capacity [Mm^3]	Area [km^2]	Gross Capacity [Mm^3]
58	70.20	0.380	0.837	0.513	1.227
59	70.30	0.397	0.877	0.527	1.279
60	70.40	0.414	0.918	0.541	1.332
61	70.50	0.431	0.961	0.556	1.387
62	70.60	0.448	1.006	0.571	1.443
63	70.70	0.465	1.053	0.586	1.501
64	70.80	0.482	1.101	0.599	1.560
65	70.90	0.499	1.151	0.614	1.621
66	71.00	0.526	1.203	0.629	1.683
67	71.10	0.564	1.260	0.645	1.747
68	71.20	0.601	1.320	0.661	1.812
69	71.30	0.638	1.384	0.677	1.879
70	71.40	0.676	1.451	0.691	1.947
71	71.50	0.713	1.522	0.705	2.017
72	71.60	0.751	1.598	0.719	2.088
73	71.70	0.788	1.676	0.731	2.161
74	71.80	0.826	1.759	0.743	2.235
75	71.90	0.863	1.845	0.756	2.310
76	72.00	0.885	1.934	0.771	2.386
77	72.10	0.890	2.023	0.784	2.464
78	72.20	0.896	2.112	0.796	2.543
79	72.30	0.902	2.203	0.809	2.623
80	72.40	0.908	2.293	0.822	2.705
81	72.50	0.914	2.385	0.834	2.787
82	72.60	0.919	2.477	0.846	2.871
83	72.70	0.925	2.569	0.858	2.957
84	72.80	0.931	2.662	0.869	3.043
85	72.90	0.937	2.756	0.879	3.130
86	73.00	0.940	2.850	0.889	3.219
87	73.10	0.940	2.944	0.899	3.308
88	73.20	0.940	3.038	0.908	3.398
89	73.30	0.940	3.132	0.918	3.490

Sr. No	Elevation (w.r.t. MSL) [m]	2016 Survey		2021 Survey	
		Area [km^2]	Gross Capacity [Mm^3]	Area [km^2]	Gross Capacity [Mm^3]
90	73.40	0.940	3.226	0.930	3.582
91	73.50	0.940	3.320	0.941	3.676
92	73.60	0.940	3.414	0.952	3.770
93	73.70	0.940	3.508	0.962	3.866
94	73.80	0.940	3.602	0.972	3.963
95	73.90	0.940	3.696	0.983	4.061
96	74.00	1.000	3.796	0.996	4.160
97	74.10	1.061	3.902	1.009	4.260

Note: Since there are mismatches between Original live and dead storage capacity given by client for the year 1982 (table showing live capacities at 0.05 m interval height) and the live and dead storage capacities given in salient features of 2016 report, the present survey results were compared with 2016 survey results only

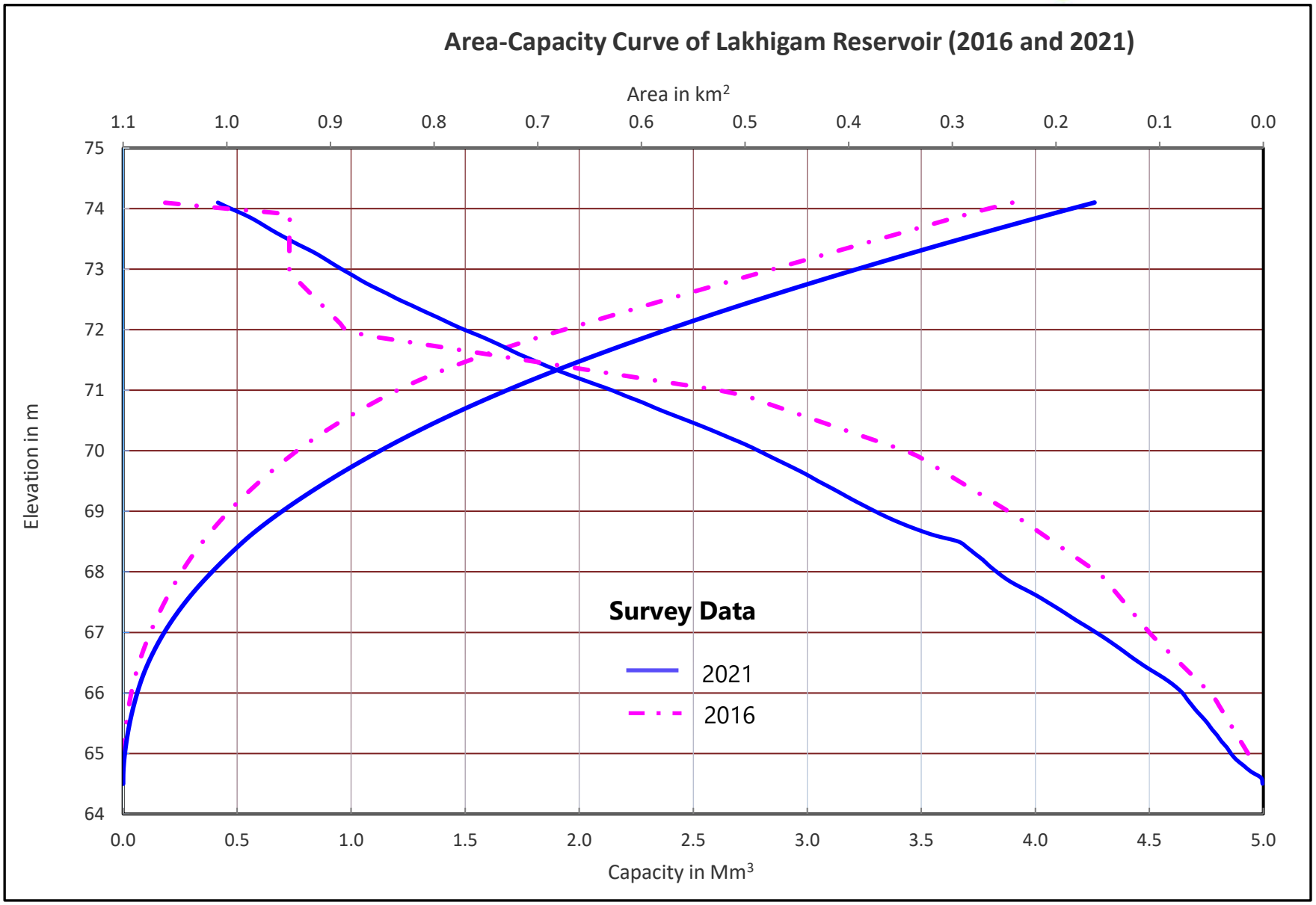

Figure 5.6: Area capacity curve for 2021 survey compared with area capacity details of 2016 survey for Lakhigam Reservoir

5.4 Sedimentation in Reservoir

The present survey of Lakhigam reservoir was carried out between April -May 2021 and August 2021. Previous survey was carried out in the year 2016. The catchment area considered for sedimentation studies is 13.34 km^2. In the present study, the age of the reservoir is considered as 5 years (2016 – 2021). As per 2021 survey, the total area of reservoir at FRL 74.10 m is 1.009 km^2 and the corresponding gross storage capacity is 4.260 Mm^3. Table 5.3 details the gross capacity loss, rate of sedimentation and annual % loss in gross storage capacity w.r.t. 2016 capacity studies.

Table 5.3: Sedimentation in Lakhigam Reservoir

Year	2016	2021
Storage Capacity in Mm^3		
Dead	0.131	0.197
Live	3.771	4.063
Gross	3.902	4.260
Loss of Storage Capacity in Mm^3		(w.r.t. 2016)
Dead	NA	-0.066
Live	NA	-0.292
Gross	NA	-0.358
Sedimentation Rate in Ham/100 km^2/Year		(w.r.t. 2016)
Dead	NA	-9.912
Live	NA	-43.771
Gross	NA	-53.682
Annual % loss		(w.r.t. 2016)
Dead	NA	-0.339
Live	NA	-1.497
Gross	NA	-1.835
Remarks	NA	Desiltation
Note: Sign Convention: -ve sign shows desiltation and +ve sign shows siltation		

Note: Since there are mismatches between Original live and dead storage capacity given by client for the year 1982 (table showing live capacities at 0.05 m interval height) and the live and dead storage capacities given in salient features of 2016 report, the present survey results were compared with 2016 survey results only.

Table 5.4 gives the results of the Trap efficiency and Sedimentation Index calculated for Lakhigam reservoir as per the methodology given in IS 12182-1987.

Table 5.4: Trap Efficiency and Sedimentation Index for Lakhigam Reservoir

Trap Efficiency	Sedimentation Index
96%	4.819×10^{11} sec^2/m

In Table 5.3, the survey data of 2016 has been compared with 2021 survey results to understand the sedimentation in Lakhigam reservoir. It may be observed that there is an increase in the storage capacity of the reservoir due to desiltation.

In comparison with 2016 survey, the present survey results indicate desiltation process in the reservoir. The reason behind the present survey results showing desiltation w.r.t. 2016 survey results could be due to change of upstream catchment characteristics. Also, there could be some anthropogenic activities in the catchment area which might result in desiltation in the reservoir.

Table 5.5: Sedimentation Volumes from Surveys of Previous Year

Sr. No.	Year of Survey	Source of Data	Period (years)	Reservoir Capacity [Mm^3]	Loss of Gross Capacity (Since 2016 survey)			Observed Rate of Sedimentation (Since 2016 survey) [Ha m / 100 Sq km/Yr]
				Gross	Mm^3	% Cumulative	Remark	
1	2016	Govt.	-	3.902	-	-	-	-
2	2021	Present Survey	5	4.260	-0.358	-9.177	Desiltation	-53.682

Note: Sign Convention: -ve sign shows desiltation

- As per 2021 survey results, the volume of sediment removed or the increase in gross storage capacity w.r.t. 2016 survey data is (-) 0.358 Mm^3.
- The rate of siltation in Lakhigam reservoir is (-) 0.072 Mm^3/year.
- The average rate of siltation in the Lakhigam reservoir during the 5 years life span (2016 – 2021), works out to (-) 53.682 Ha m/100 sq km^2/year.
- The annual % loss in Lakhigam reservoir during the 5 years life span is (-) 1.835 % indicating desiltation process in reservoir.
- Trap Efficiency and sedimentation Index calculated for Lakhigam reservoir as per methodology give in IS 12182-1987 is 96% and 4.819 x 10^{11} sec^2/m respectively.

Note: The negative sign for sedimentation rate, average rate of siltation and Annual % loss indicates desiltation in reservoir w.r.t. 2016 survey results

Table 5.6 gives the gross, live and dead storage capacity from bed level to FRL at 0.1 m interval.

Table 5.6: Gross, Live and Dead storage capacity from bed level to FRL at 0.1 m interval

Gross, Live and Dead storage capacity from bed level to FRL at 0.1 m interval - Lakhigam reservoir					
Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
1	64.50	0.0000	--	0.0000	Bed level
2	64.60	0.0002	--	0.0002	--
3	64.70	0.0008	--	0.0008	--
4	64.80	0.002	--	0.002	--
5	64.90	0.005	--	0.005	--
6	65.00	0.007	--	0.007	--
7	65.10	0.011	--	0.011	--
8	65.20	0.015	--	0.015	--
9	65.30	0.019	--	0.019	--
10	65.40	0.024	--	0.024	--
11	65.50	0.029	--	0.029	--
12	65.60	0.034	--	0.034	--
13	65.70	0.041	--	0.041	--
14	65.80	0.047	--	0.047	--
15	65.90	0.054	--	0.054	--
16	66.00	0.062	--	0.062	--
17	66.10	0.070	--	0.070	--
18	66.20	0.079	--	0.079	--
19	66.30	0.088	--	0.088	--
20	66.40	0.099	--	0.099	--
21	66.50	0.111	--	0.111	--
22	66.60	0.123	--	0.123	--
23	66.70	0.136	--	0.136	--
24	66.80	0.150	--	0.150	--
25	66.90	0.165	--	0.165	--
26	67.00	0.181	--	0.181	--
27	67.10	0.197	--	0.197	MDDL
28	67.20	0.215	0.018	0.197	--
29	67.30	0.233	0.036	0.197	--
30	67.40	0.253	0.055	0.197	--

Gross, Live and Dead storage capacity from bed level to FRL at 0.1 m interval - Lakhigam reservoir					
Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
31	67.50	0.273	0.076	0.197	--
32	67.60	0.294	0.097	0.197	--
33	67.70	0.317	0.119	0.197	--
34	67.80	0.340	0.143	0.197	--
35	67.90	0.365	0.167	0.197	--
36	68.00	0.390	0.193	0.197	--
37	68.10	0.416	0.219	0.197	--
38	68.20	0.443	0.246	0.197	--
39	68.30	0.470	0.273	0.197	--
40	68.40	0.498	0.301	0.197	--
41	68.50	0.527	0.330	0.197	--
42	68.60	0.558	0.361	0.197	--
43	68.70	0.590	0.393	0.197	--
44	68.80	0.625	0.427	0.197	--
45	68.90	0.660	0.463	0.197	--
46	69.00	0.697	0.500	0.197	--
47	69.10	0.735	0.538	0.197	--
48	69.20	0.774	0.577	0.197	--
49	69.30	0.814	0.617	0.197	--
50	69.40	0.856	0.659	0.197	--
51	69.50	0.898	0.701	0.197	--
52	69.60	0.942	0.744	0.197	--
53	69.70	0.986	0.789	0.197	--
54	69.80	1.032	0.835	0.197	--
55	69.90	1.079	0.882	0.197	--
56	70.00	1.127	0.930	0.197	--
57	70.10	1.176	0.979	0.197	--
58	70.20	1.227	1.030	0.197	--
59	70.30	1.279	1.082	0.197	--
60	70.40	1.332	1.135	0.197	--
61	70.50	1.387	1.190	0.197	--

Gross, Live and Dead storage capacity from bed level to FRL at 0.1 m interval - Lakhigam reservoir					
Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
62	70.60	1.443	1.246	0.197	--
63	70.70	1.501	1.304	0.197	--
64	70.80	1.560	1.363	0.197	--
65	70.90	1.621	1.424	0.197	--
66	71.00	1.683	1.486	0.197	--
67	71.10	1.747	1.550	0.197	--
68	71.20	1.812	1.615	0.197	--
69	71.30	1.879	1.682	0.197	--
70	71.40	1.947	1.750	0.197	--
71	71.50	2.017	1.820	0.197	--
72	71.60	2.088	1.891	0.197	--
73	71.70	2.161	1.964	0.197	--
74	71.80	2.235	2.037	0.197	--
75	71.90	2.310	2.112	0.197	--
76	72.00	2.386	2.189	0.197	--
77	72.10	2.464	2.267	0.197	--
78	72.20	2.543	2.346	0.197	--
79	72.30	2.623	2.426	0.197	--
80	72.40	2.705	2.507	0.197	--
81	72.50	2.787	2.590	0.197	--
82	72.60	2.871	2.674	0.197	--
83	72.70	2.957	2.759	0.197	--
84	72.80	3.043	2.846	0.197	--
85	72.90	3.130	2.933	0.197	--
86	73.00	3.219	3.021	0.197	--
87	73.10	3.308	3.111	0.197	--
88	73.20	3.398	3.201	0.197	--
89	73.30	3.490	3.293	0.197	--
90	73.40	3.582	3.385	0.197	--
91	73.50	3.676	3.479	0.197	--
92	73.60	3.770	3.573	0.197	--

Gross, Live and Dead storage capacity from bed level to FRL at 0.1 m interval - Lakhigam reservoir					
Sr. No.	Elevation [m]	Gross Capacity [Mm^3]	Live Capacity [Mm^3]	Dead Capacity [Mm^3]	Remarks
93	73.70	3.866	3.669	0.197	--
94	73.80	3.963	3.766	0.197	--
95	73.90	4.061	3.863	0.197	--
96	74.00	4.160	3.962	0.197	--
97	74.10	4.260	4.063	0.197	FRL

6. Conclusions

- The reservoir topography was uneven, with reservoir bed level ranging from 64.50 m to 74.10 m w.r.t. MSL. The lowest reservoir bed level 64.50 m 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 in east, west and south directions away from the dam wall within the survey area.
- Current survey results indicate that there is an increase in gross storage capacity (w.r.t. 2016 project data) due to desiltation in Lakhigam reservoir is (-) 0.358 Mm^3. The probable reasons for the increase of gross storage 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 desiltation of the reservoir.
- In comparison with 2016 survey results, 2021 results indicate increase in storage capacity due to desiltation. The annual % loss in gross storage capacity indicates (-) 1.835 % desiltation process in reservoir.
- The sedimentation volumes, sedimentation rates, loss of storage capacity, trap efficiency, sedimentation index have been reported in the study. Moreover, the tables for gross, live and dead storage capacity of reservoir at every 0.1 m interval from lowest bed level to FRL 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	
26 April 2021	Survey personnel and equipment with survey boat 'Fugro Zodiac' reached Lakhigam reservoir. Fugro Zodiac deployed on Lakhigam reservoir and mobilization and calibration / verification commenced
27 - 29 April 2021	Calibration / verification in progress
30 April 2021	Calibration / verification completed and Bathymetry survey commenced.
01 May 2021	Bathymetry Survey completed.
02 May 2021	Site visit and reconnaissance survey completed to Dev dam.
03 May 2021	Demobilization of Survey equipment commenced and completed
Topography Survey	
8 August 2021	Topography survey team with equipment reached Lakhigam Dam. Mobilisation and calibration commenced and completed. Topography survey commenced and completed

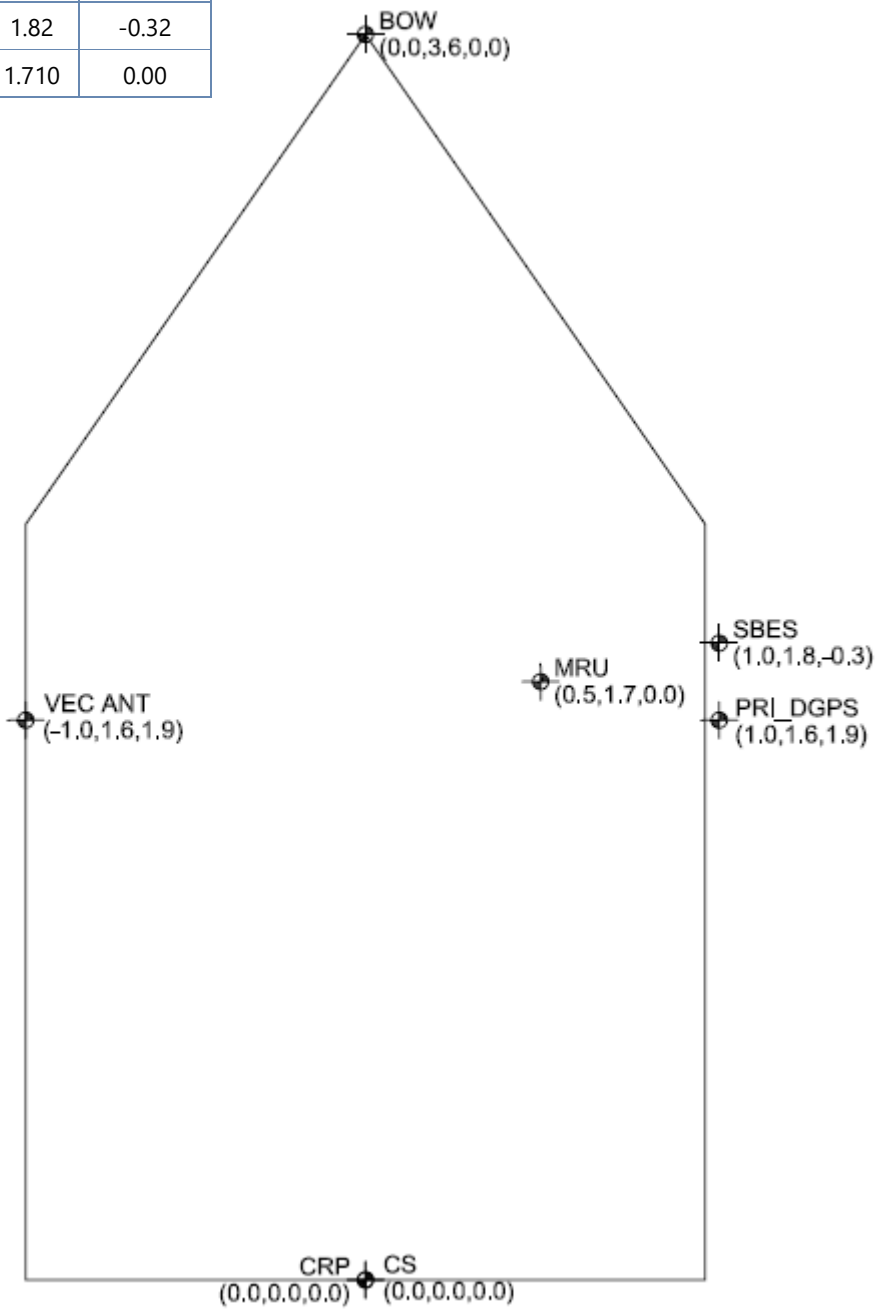
Appendix B

Survey Vessel Sensor Offsets

(01 Page)

Survey Vessel 'Fugro Zodiac' Sensor Offset Diagram

Sensor Offsets: Fugro Zodiac			
Starfix.Suite Name	**X [m]**	**Y [m]**	**Z [m]**
Centre Stern (CS)	0.00	0.00	0.00
Bow	0.00	3.56	0.00
PRI_GPS	1.01	1.60	1.90
VEC_ANT	-0.97	1.60	1.90
SBES	1.01	1.82	-0.32
MRU	0.50	1.710	0.00

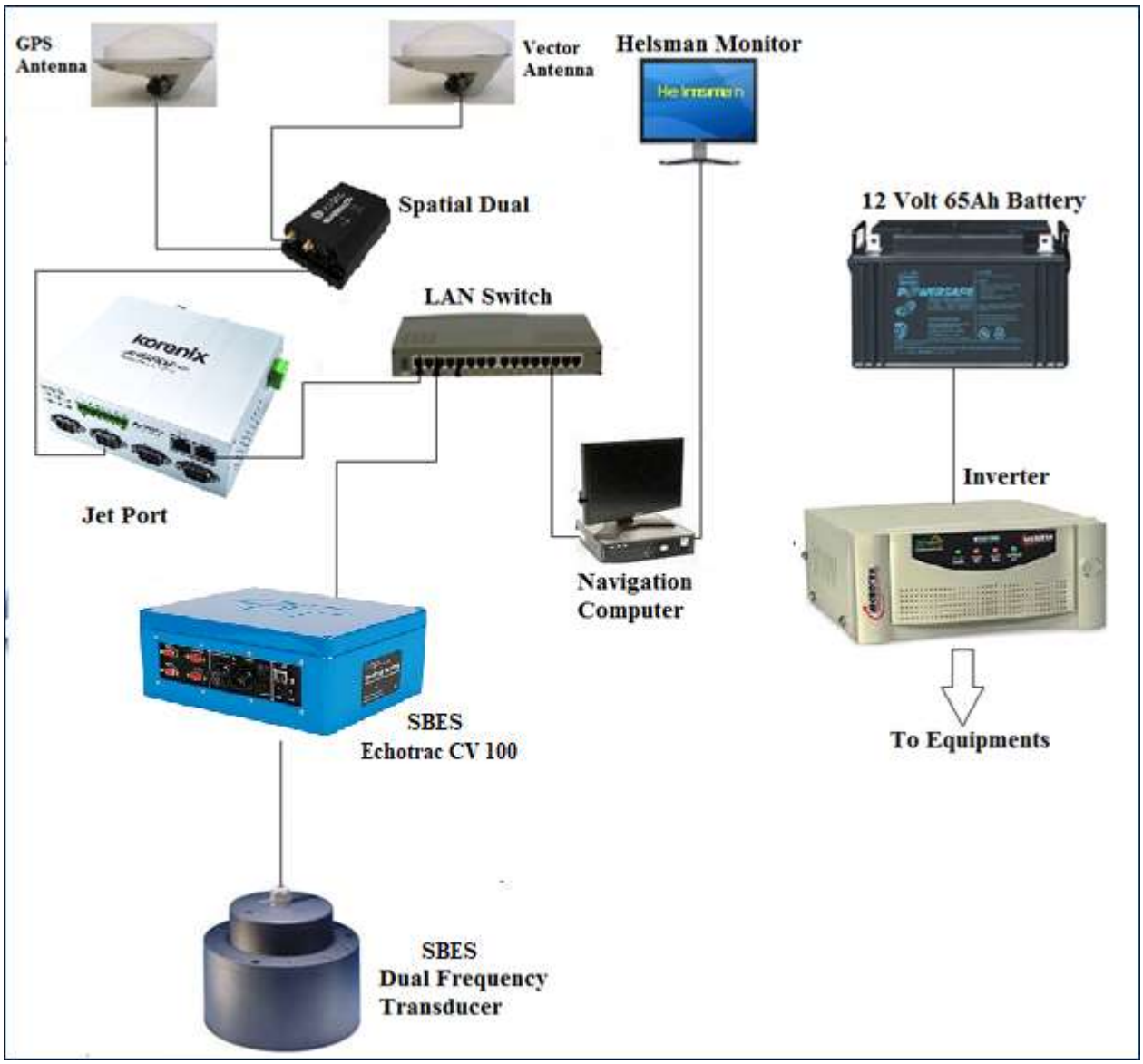


Appendix C

Equipment Layout Diagram

(01 Page)

Equipment Layout Diagram onboard Fugro Zodiac



Appendix D

Results of Field Calibrations / Verifications

(20 pages)

FUGRO SURVEY (INDIA) PVT. LTD.

Diagram Report of LAKHI DAM TBM1

Job No. :	J-HYD-20-174630	**Job Name:**	Bathymetric Survey
Station Name:	LAKHI DAM TBM1	**Location:**	LAKHIGAM DAM, Gujarat
Party Chief :	Pritam Seth	**Job Engineer/Surveyor :**	Atul Bhoyte.
Date of Observation: (Date & Time)	29-04-2021 & 16:42hrs	**End of Observation: (Date & Time)**	29-04-2021 & 17:12hrs

1. Station Name: LAKHI DAM TBM1**.**

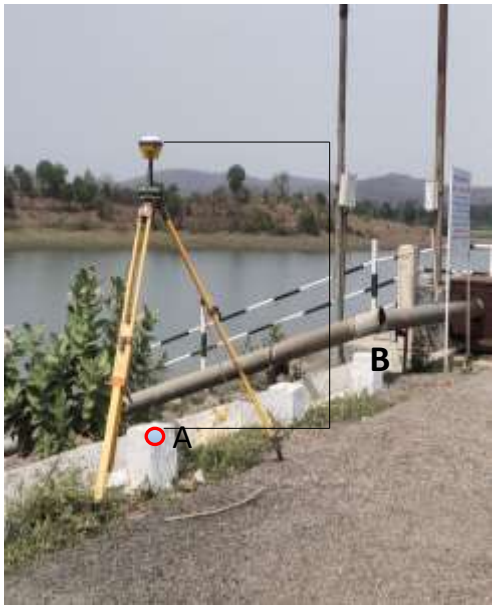
Positioning System Verification Results						
World Geodetic System 84, UTM Projection, CM 075º East, Zone 43 North						
Sensor	**Serial No.**	**Starfix.Seis Name**	**Method**	**File Type**	**Mean Differences**	**SD**
TRIMBLE BX992 RECEIVER	025-00009601	PRI_DGPS	Mean position report	FBF	NA	0.02

A=Center Point of LAKHI DAM TBM1 Height from MSL 78.688m

B= Antenna Height from BM 1.302m (Measure by Tape)

Ellipsoidal height of Antenna= 20.584m

Ellipsoidal Height of BM 20.584m - 1.302m=19.282m



Position Of Antenna:-

Latitude: 21°19’39.161”N, Longitude: 073°21’08.251”E

Easting: 3,29,114.621m E, Northing: 23,59,292.459m N

Prepared By: Pritam Seth.

BATHYMETRY
MEAN POSITION REPORT

Project ID	J-HYD-20-174630		
Location	LAKHI DAM, CENTRAL GUJRAT		
Client	GOVERMENT OF GUJRAT	**Vessel**	Tripod
Comment	STN HT 1.302m LAKHI DAM TBM1		

Session Name: MPR-20210429084103-v1 Records Used: 1738 of 1799

Start Time: 29 Apr 2021, 16:42:50+05:30 End Time: 29 Apr 2021, 17:12:49+05:30 Session Length: 00:29:59

Mean Position for Tripod CommonReferencePoint		
	WGS 84 / UTM zone 43N	**WGS 84(2D)**
Latitude	21°19'39.16142"N	21°19'39.16142"N
Longitude	073°21'08.25191"E	073°21'08.25191"E
Height	20.584m Ell.	20.584m Ell.
Easting	3,29,114.621m E (SD: ±0.02m)	
Northing	23,59,292.459m N (SD: ±0.01m)	
Height	81.515m 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

STN HT 1.302m LAKHI DAM TBM1

Pritam Seth
Party Chief
FSINPVT (Fugro Survey (India) Pvt Ltd.)

Deputy Executive Engineer
LAKHINGAM DAM
GOVERMENT OF GUJRAT

Geodetic Parameters

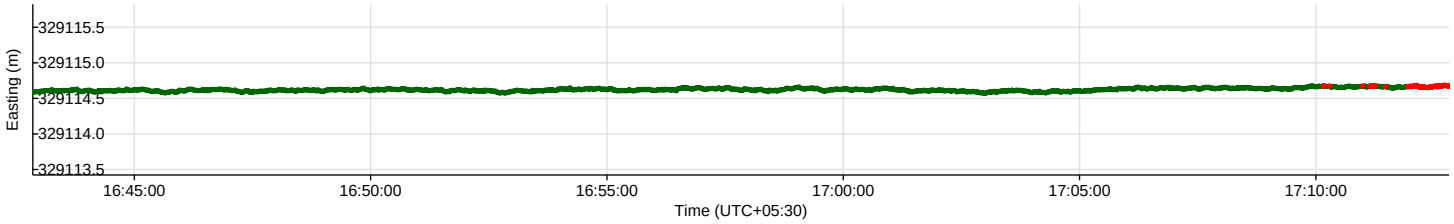
Name : WGS 84 / UTM zone 43N		
EPSG Code	EPSG::32643	
Local Geodetic Datum Parameters		
Datum	World Geodetic System 1984	EPSG::6326
Ellipsoid	WGS 84	
Semi major axis	a = 63,78,137.000 m	
Inverse flattening	1/f = 298.257223563	
Local Projection Parameters		
Map Projection	Transverse Mercator	
Grid System	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	

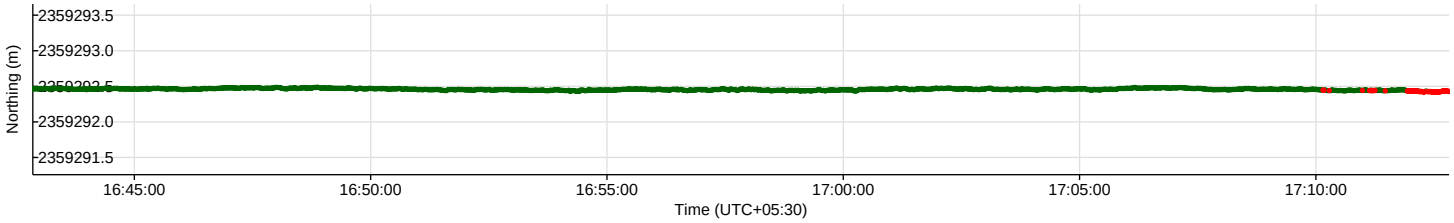
Scatter Plot

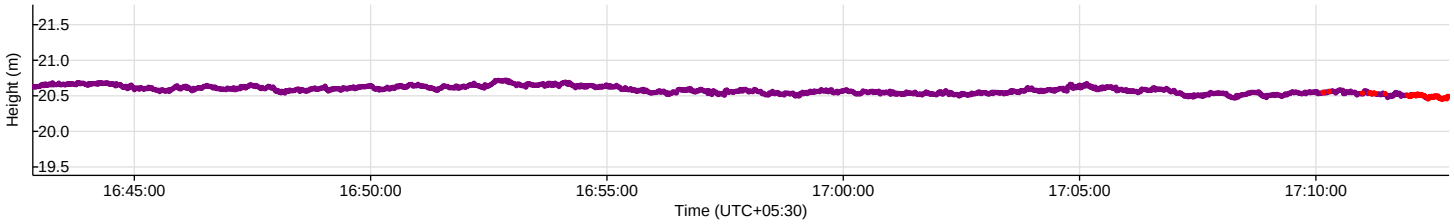
Mean Position

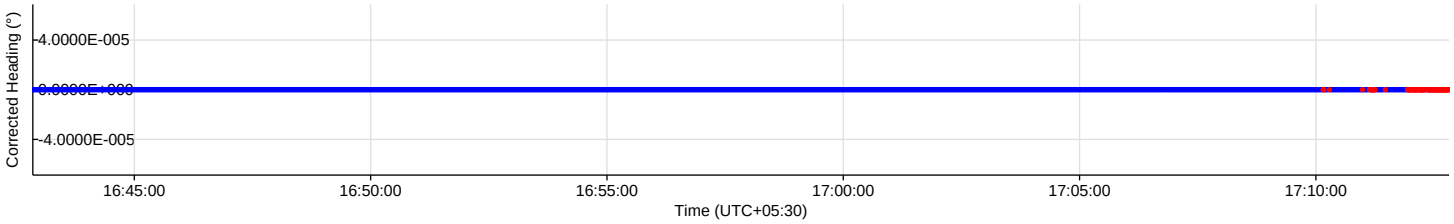
	Easting	Northing
Tripod	3,29,114.621m E	23,59,292.459m N

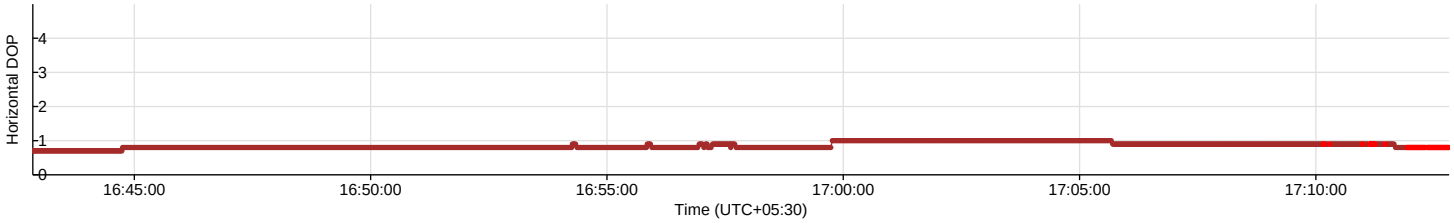
Time Series Plots for Tripod

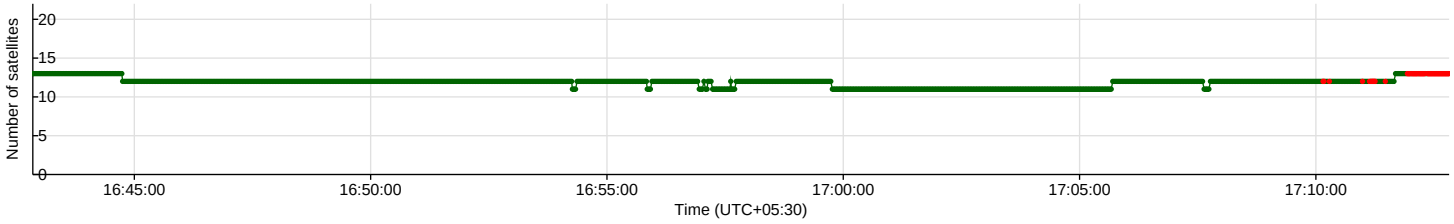


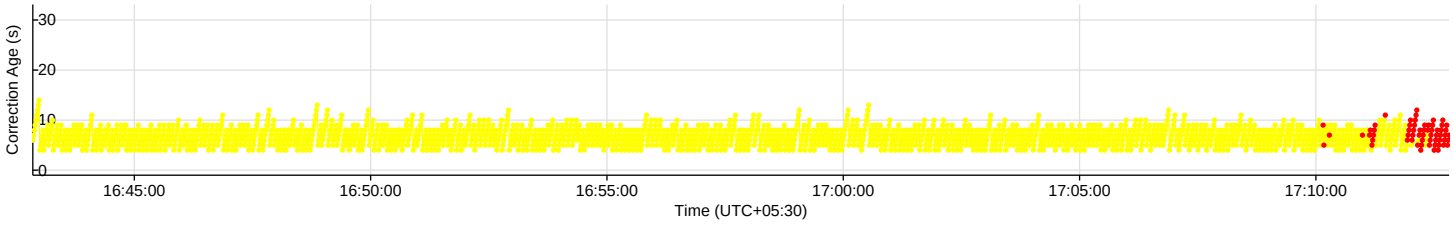












FUGRO SURVEY (INDIA) PVT. LTD.

Diagram Report of LAKHI DAM TBM1

Job No. :	J-HYD-20-174630	**Job Name:**	Bathymetric Survey
Station Name:	**LAKHI DAM TBM1**	**Location:**	LAKHIGAM DAM, Gujarat
Party Chief :	Pritam Seth	**Job Engineer/Surveyor :**	Atul Bhoyte.
Date of Observation: (Date & Time)	29-04-2021 & 17:45hrs	**End of Observation: (Date & Time)**	29-04-2021 & 18:15hrs

1. Station Name: LAKHI DAM TBM1.

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**
SATIAL DUAL RECEIVER	025-00006405	PRI_DGPS	Mean position report	FBF	NA	0.01

A=Center Point of **LAKHI DAM TBM1** Height from MSL 78.688m

B= Antenna Height from BM 1.260m (Measure by Tape)

Ellipsoidal height of Antenna= 20.592m

Ellipsoidal Height of BM 20.592 - 1.260m=19.332m

Position Of Antenna:-

Latitude: 21°19’39.162”N, **Longitude:** 073°21’08.252”E

Easting: 3,29,114.631m E**, Northing:** 23,59,292.484m N

Prepared By: Pritam Seth.

BATHYMETRY
MEAN POSITION REPORT

Project ID	J-HYD-20-174630		
Location	LAKHI DAM, CENTRAL GUJRAT		
Client	GOVERMENT OF GUJRAT	**Vessel**	Tripod
Comment	STN HT 1.260m LAKHI DAM TBM1 SD		

Session Name: MPR-20210429115618-v1 Records Used: 1756 of 1799

Start Time: 29 Apr 2021, 17:45:55+05:30 End Time: 29 Apr 2021, 18:15:54+05:30 Session Length: 00:29:59

Mean Position for Tripod CommonReferencePoint		
	WGS 84 / UTM zone 43N	**WGS 84(2D)**
Latitude	21°19'39.16225"N	21°19'39.16225"N
Longitude	073°21'08.25225"E	073°21'08.25225"E
Height	20.592m Ell.	20.592m Ell.
Easting	3,29,114.631m E (SD: ±0.01m)	
Northing	23,59,292.484m N (SD: ±0.01m)	
Height	81.523m Ort. (SD: ±0.02m 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

STN HT 1.260m LAKHI DAM TBM1 SD

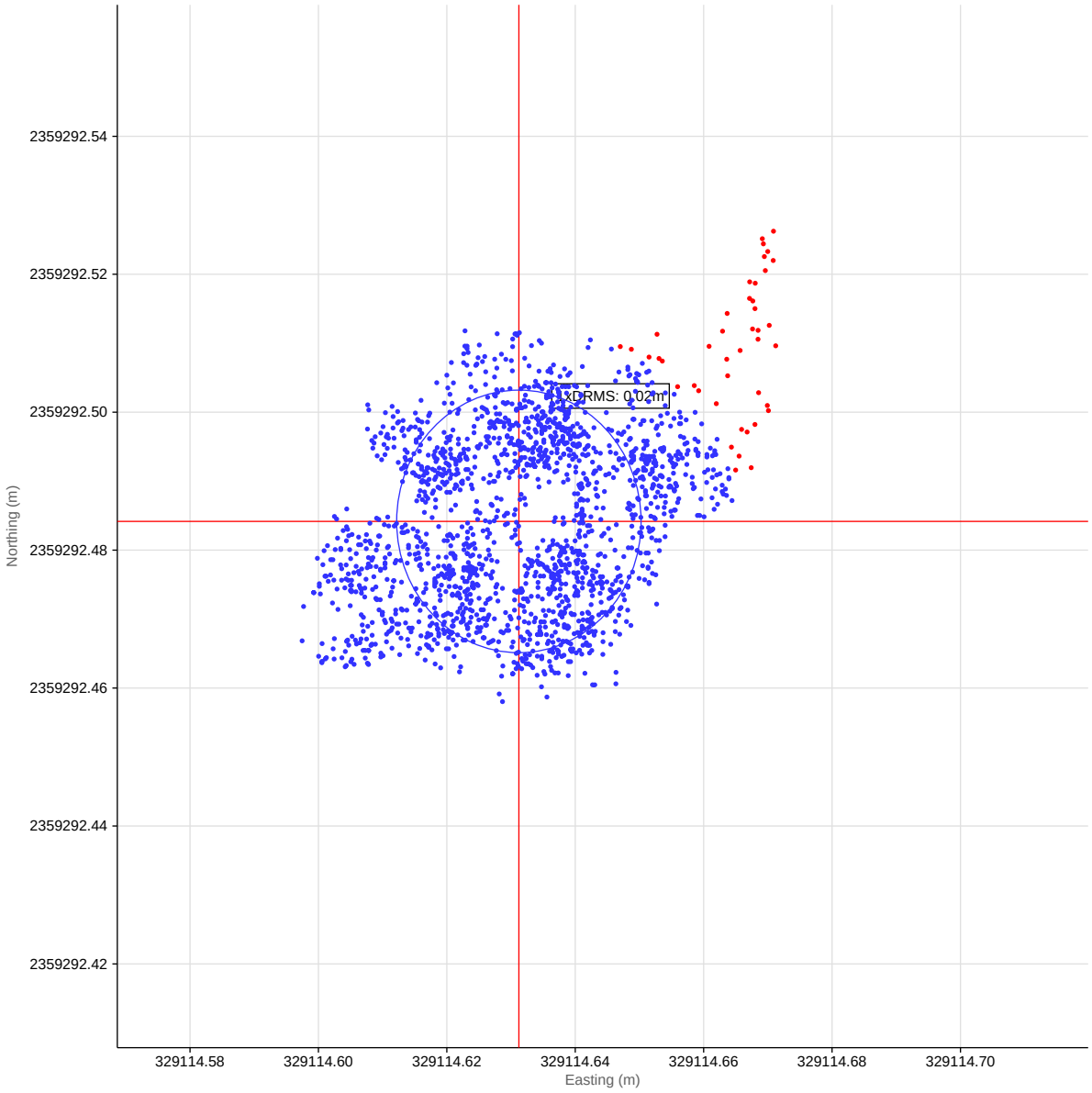
Pritam Seth
Party Chief
FSINPVT (Fugro Survey (India) Pvt Ltd.)

Deputy Executive Engineer
LAKHIGAM DAM
GOVERMENT OF GUJRAT

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	

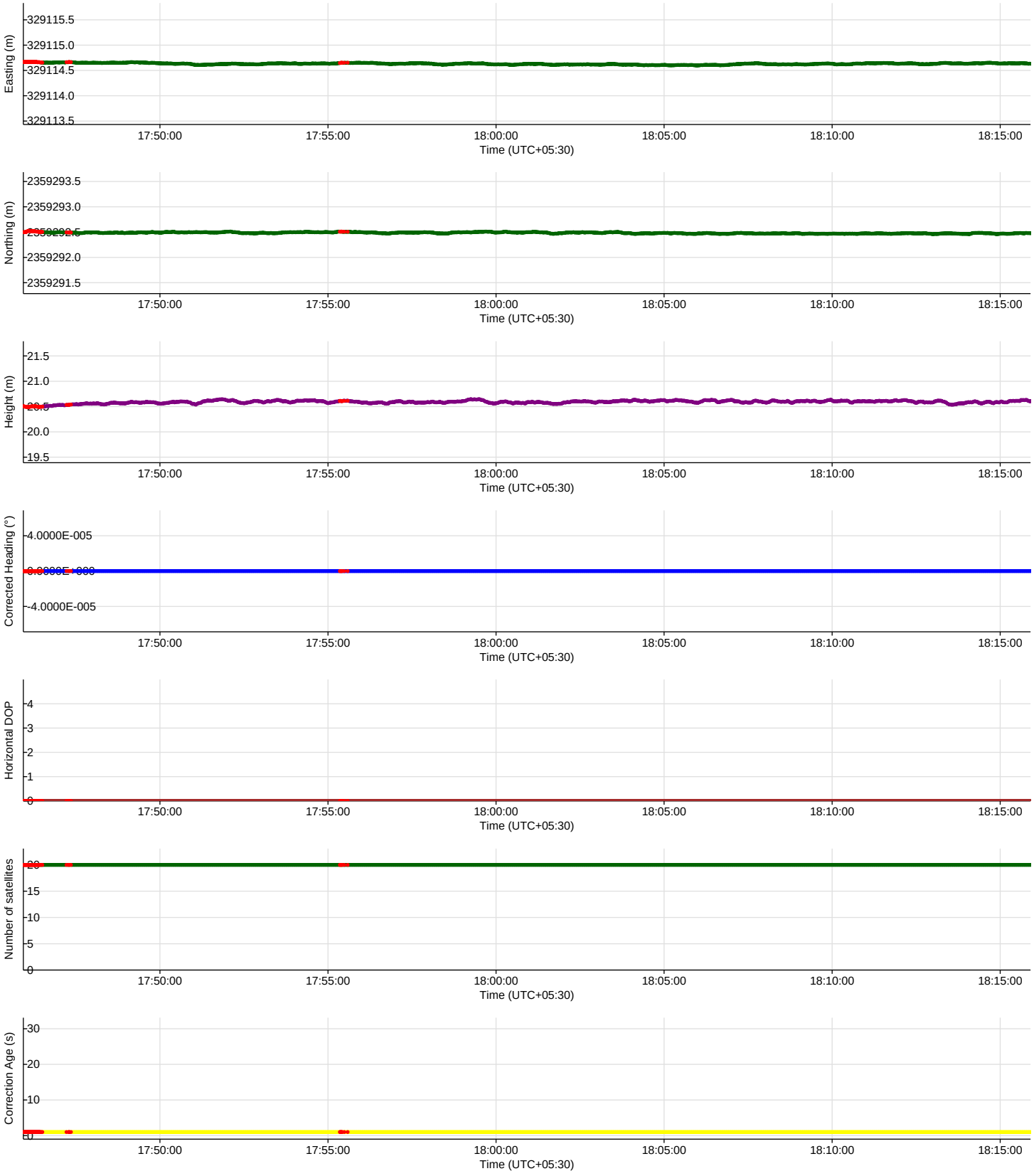
Scatter Plot



Mean Position

	Easting	Northing
Tripod	3,29,114.631m E	23,59,292.484m N

Time Series Plots for Tripod



FUGRO SURVEY (INDIA) PVT. LTD.

Diagram Report of LAKHI DAM TBM2

Job No. :	J-HYD-20-174630	**Job Name:**	Bathymetric Survey
Station Name:	**LAKHI DAM TBM2**	**Location:**	LAKHIGAM DAM, Gujarat
Party Chief :	Pritam Seth	**Job Engineer/Surveyor :**	Atul Bhoyte.
Date of Observation: (Date & Time)	29-04-2021 & 13:27hrs	**End of Observation: (Date & Time)**	29-04-2021 & 13:57hrs

1. Station Name: LAKHI DAM TBM2.

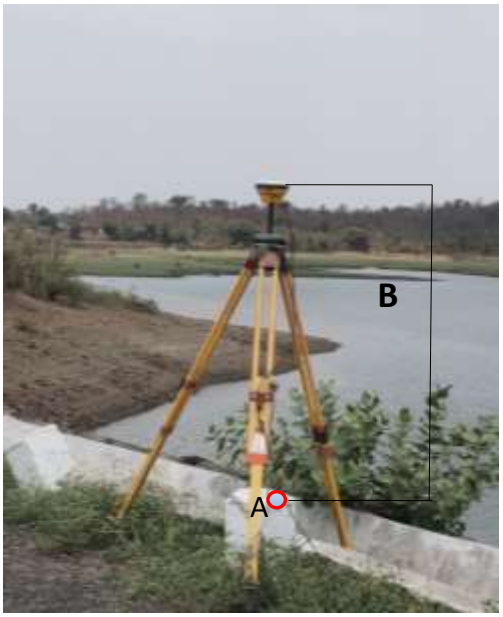
Positioning System Verification Results						
World Geodetic System 84, UTM Projection, CM 075º East, Zone 43 North						
Sensor	**Serial No.**	**Starfix.Seis Name**	**Method**	**File Type**	**Mean Differences**	**SD**
Trimble BX 992 RECEIVER	025-00009601	PRI_DGPS	Mean position report	FBF	NA	0.02

A=Center Point of LAKHI DAM TBM2 Height from MSL 78.577m

B= Antenna Height from BM 1.282m (Measure by Tape)

Ellipsoidal height of Antenna= 20.560m

Ellipsoidal Height of BM 20.560m - 1.282m=19.278m



Position Of Antenna:-

Latitude: 21°19’38.867”N, **Longitude:** 073°21’07.196”E

Easting: 3,29,084.111m E**, Northing:** 23,59,283.740m N

Prepared By: Pritam Seth.

BATHYMETRY
MEAN POSITION REPORT

Project ID	J-HYD-20-174630		
Location	LAKHI DAM, CENTRAL GUJRAT		
Client	GOVERMENT OF GUJRAT	**Vessel**	Tripod
Comment	STN HT 1.282m LAKHI DAM TBM 2		

Session Name: MPR-20210429070352-v1 Records Used: 1663 of 1797

Start Time: 29 Apr 2021, 13:27:11+05:30 End Time: 29 Apr 2021, 13:57:10+05:30 Session Length: 00:29:59

Mean Position for Tripod CommonReferencePoint		
	WGS 84 / UTM zone 43N	**WGS 84(2D)**
Latitude	21°19'38.86756"N	21°19'38.86756"N
Longitude	073°21'07.19633"E	073°21'07.19633"E
Height	20.560m Ell.	20.560m Ell.
Easting	3,29,084.111m E (SD: ±0.02m)	
Northing	23,59,283.740m N (SD: ±0.02m)	
Height	81.491m Ort. (SD: ±0.05m Ort.)	

Sensors	**Sensor Averages**	**SD**
Heading	334.75°T 335.35°G	±79.3°
Pitch		
Roll		
Depth (Sounder)	0.0m	±0.00m
Depth (Manual)	0.0m	N/A

STN HT 1.282M LAKHI DAM TBM 2

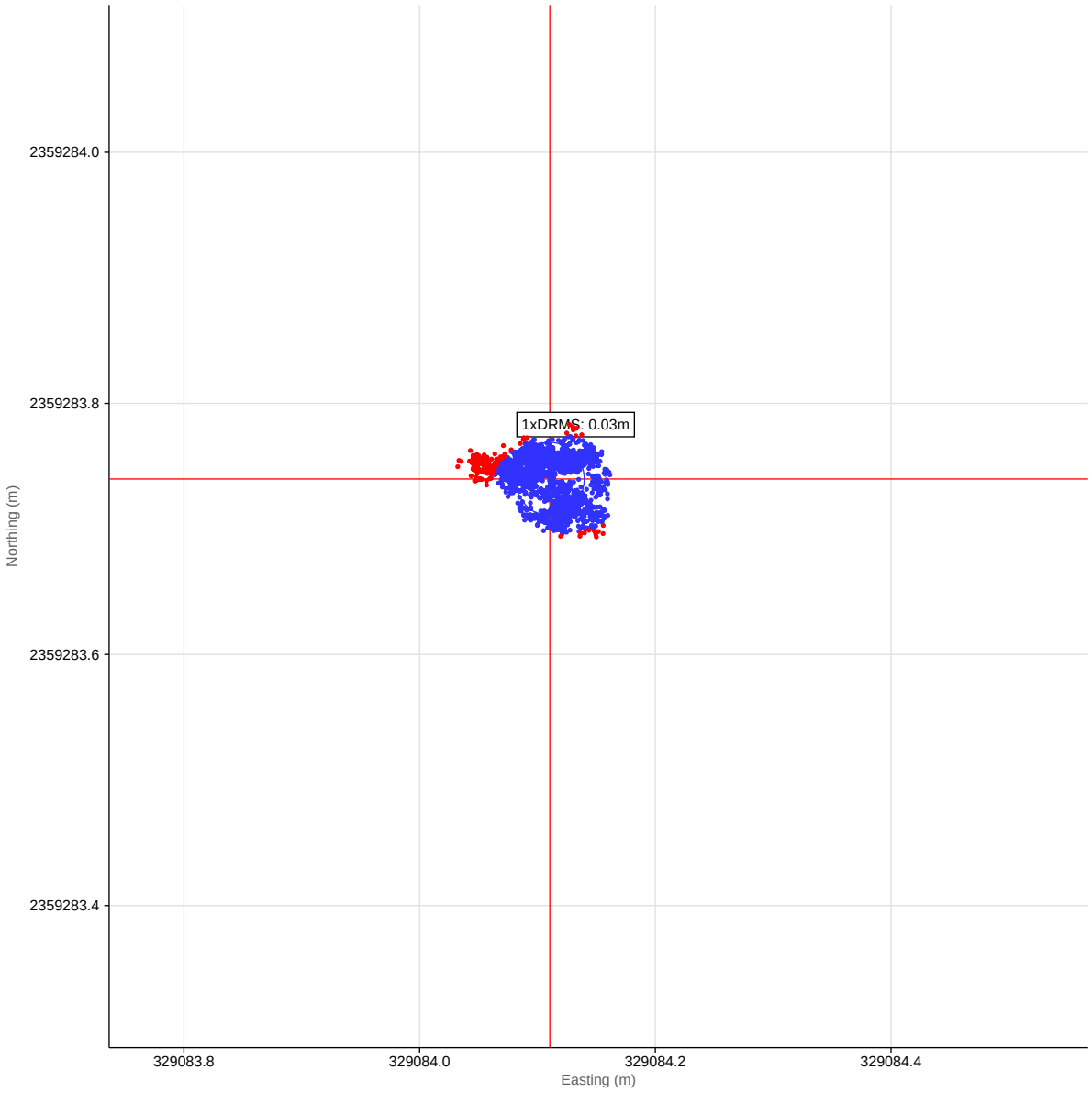
Pritam Seth
Party Chief
FSINPVT (Fugro Survey (India) Pvt Ltd.)

Deputy Executive Engineer
LAKHIGAM DAM
GOVERMENT OF GUJRAT

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	

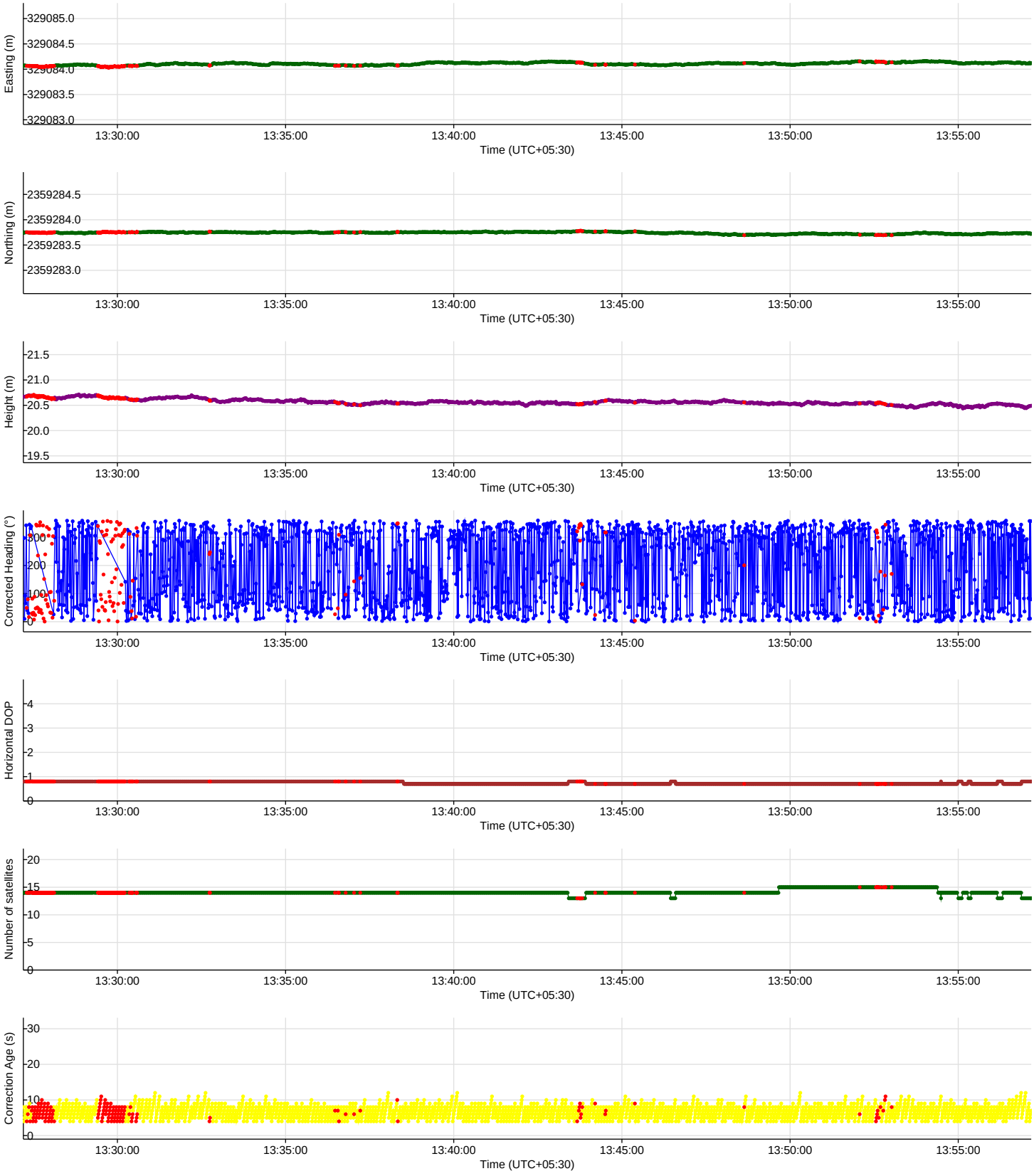
Scatter Plot



Mean Position

	Easting	Northing
Tripod	3,29,084.111m E	23,59,283.740m N

Time Series Plots for Tripod



Station Name: LAKHIGAM DAM

Positioning System Verification With BX-992 Reciever and Spatial Dual In LAKHI DAM TBM1						
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	329,114.62	2,359,292.46	21°19'39.16142"N	073°21'08.25191"E	19.282
Spatial Dual	025-00006405	329,114.631	2,359,292.484	21°19'39.16225"N	073°21'08.25225"E	19.332
	Difference	**-0.010**	**-0.025**	**--**	**--**	**-0.05**

SBES Calibration

SBES Barcheck Correction Table

Project No.	Project Title:	Vessel:	Place:
J-HYD-20-174630	**Bathymetry Survey**	**FUGRO ZODIAC**	**LAKHIGAM DAM**
Date:	Time:	Client:	
30-Apr-21	**12:45**	**GOVT. OF GUJARAT**	
Observed By: PRITAM SETH		Echo Sounder Model and SL. No.	Area Depth
Project No. J-HYD-20-174630		**ODOM ECHOTRAC CV 100/ 007169**	**4.3**

Echo Sounder Settings

Draft HI	**Draft LO**	**Sound Velocity**	
0.32	**0.32**	**Average**	**Upto Depth**
		1508.9	**4.3**
Barcheck Frequency selected	**Survey Frequency:**	Manufacturer's Accuracy	
High 210 KHz	**33 and 210 KHz**	0.10 % of Depth	0.00 m

Observations while lowering			**Observations while hoisting**		
Bar Depth (m)	ES Reading (m)	Difference (m)	Bar Depth (m)	ES Reading (m)	Difference (m)
1	1.01	-0.01	4	4.02	-0.02
2	2.01	-0.01	3.5	3.51	-0.01
2.5	2.5	0	3	2.99	0.01
3	2.99	0.01	2.5	2.5	0
3.5	3.51	-0.01	2	2	0
4	4.02	-0.02	1	0.99	0.01

	Average	-0.01	Average	0.00
	Std. Dev	0.0103	Std. Deviation	0.0117
			Cumulative Average	0.00
			Cumulative Std. Deviation	0.0010

Partychief
Pritam Seth
FSINPVT

Deputy Executive Engineer
LAKHIGAM DAM
Govt. of Gujarat

Report No:	Rev No:	Prepared	Checked	Client Rep.
###	0			

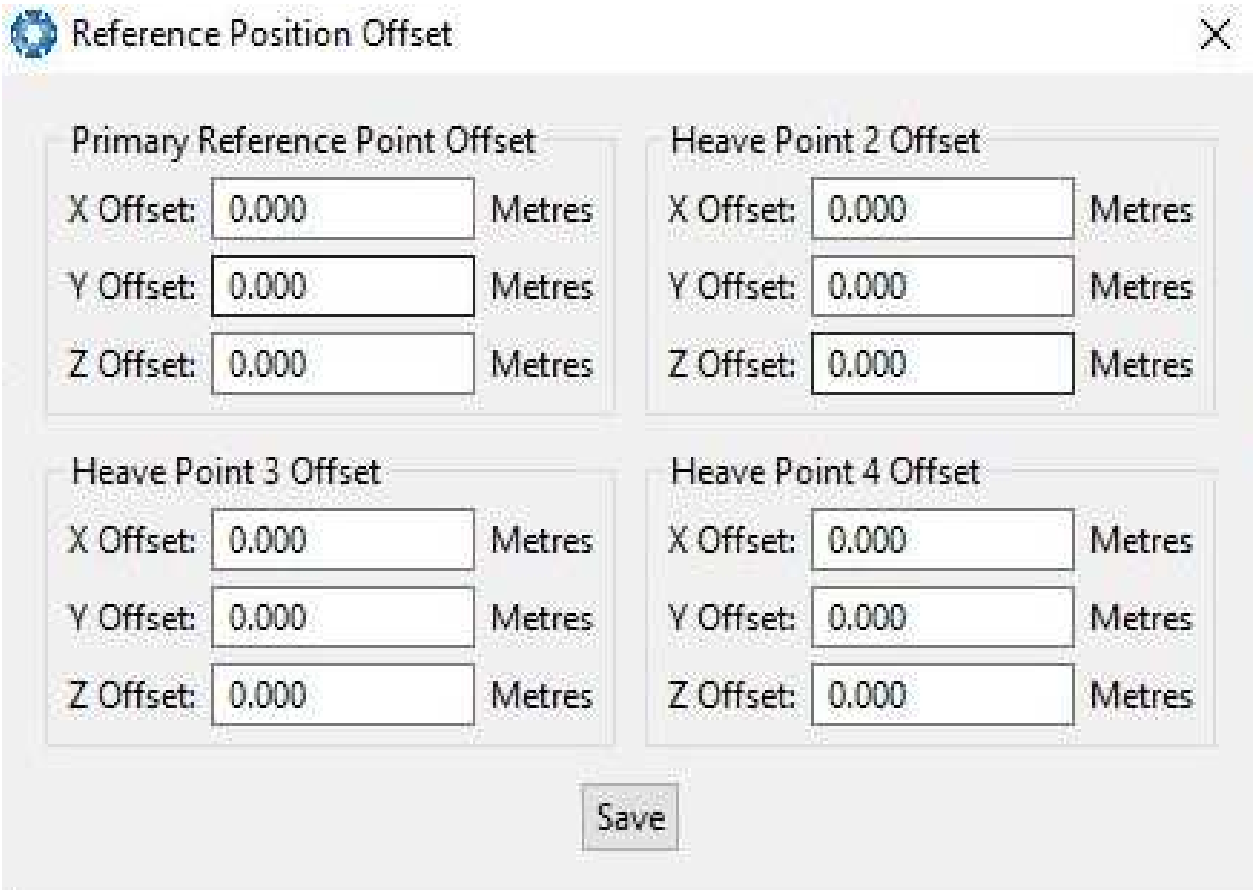
Report on Motion Sensor Calibration at sea by 'Free-Float' Method

Job No:	**J-HYD-20-174630**
Job Title:	**Bathymetric Survey**
Vessel Name:	**Fugro Zodiac**
Client Name:	**Govt. Of Gujarat**

Spatial Dual Set up:-

The instrument was placed on a plain surface Near Single beam Echosunder of the vessel and secured firmly in place.
Instrument has kept for 5 minutes to acquire accurate solution. Spatial Dual's Motion is always on fully automatic.

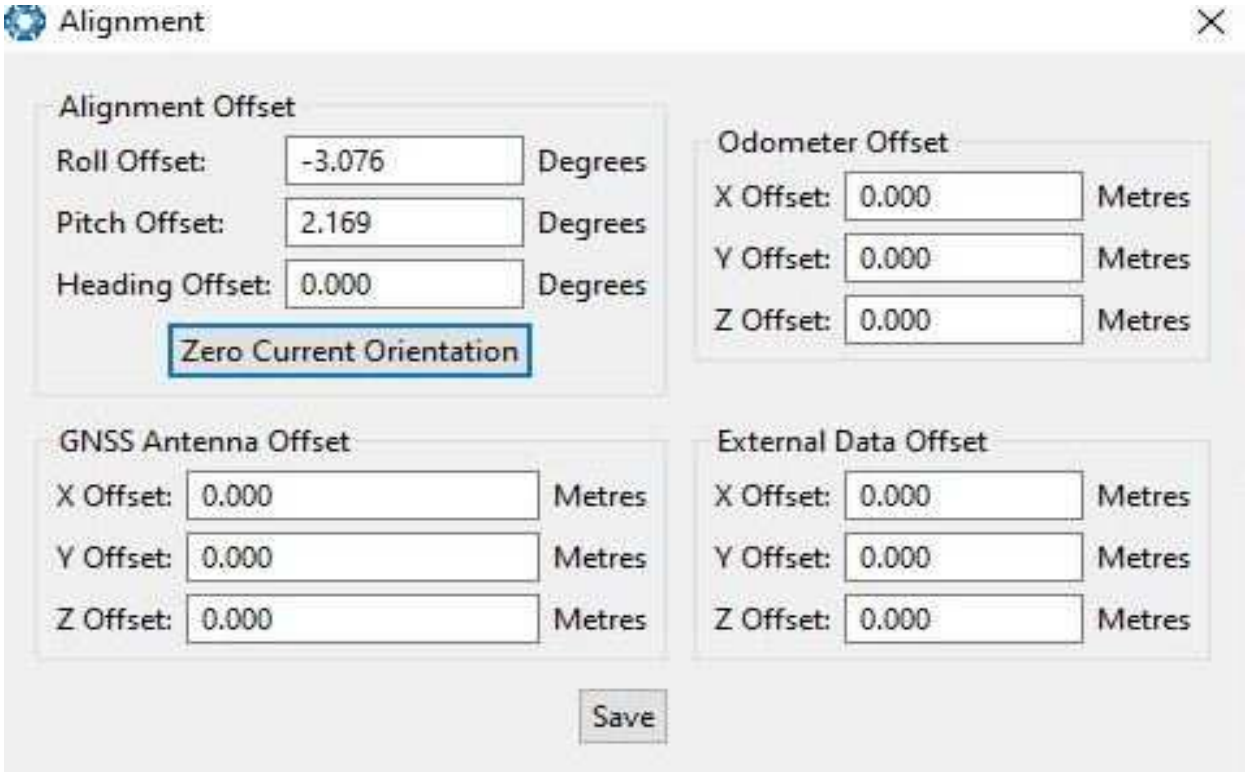
Screen Shot of Spatial Dual Manager software



Calibration by 'Free-Float' Method:-

Spatial Dual Manager Terminal progam was choosen to observe the sensor.
The vessel was then allowed to float freely for 15 minutes and the data output by the motion sensor was observed.

Pre Zero-Orientation Screen Shot of the Spatial Dual Alignment



Spatial Dual Motion has been "Zero-Oriented" by clicking "Zero current Orientation" Option in Spatial Dual manager software.

Pritam Seth
FSINPVT Party Chief
Date: 30/04/2021

Atul Bhoyte
Engineer
Date: 30/04/2021

Narmada, Water Resources, Water Supply and Kalpsar Department
WRD (Water Resources)

Location Name:	Lakhigam Dam	Date:	08/08/2021	Instrument Name	CHC
Work:	RTK Observation by Topography Team			Model no.	I 80

Station Name		Observation Duration	Easting (mE)	Northing (mN)	Local Height w.r.t MSL (m)	Remarks
TBM-2	By rover 1	2 sec	329083.998	2359283.723	78.601	XYZ Value generated by RTK of Topography Team, Base station was on Lakhi Dam TBM-1 (Fugro provided XYZ value)
TBM-2	By rover 2	2 sec	329084.001	2359283.714	78.579	XYZ Value generated by RTK of Topography Team, Base station was on Lakhi Dam TBM-1 (Fugro provided XYZ value)
TBM-2	By rover 3	2 sec	329084.005	2359283.707	78.594	XYZ Value generated by RTK of Topography Team, Base station was on Lakhi Dam TBM-1 (Fugro provided XYZ value)

		Fugro Provided XYZ Value								Difference With Fugro Provided XYZ Value		
Station Name	Remarks	Easting (mE)	Northing (mN)	Local Height w.r.t MSL (m)	Station Name	Remarks	Easting (mE)	Northing (mN)	Local Height w.r.t MSL (m)	Easting (mE)	Northing (mN)	Local Height w.r.t MSL (m)
TBM-2	Fugro Provided Value	329084.111	2359283.740	78.577	TBM-2	Check by Rover 1	329083.998	2359283.723	78.601	0.113	0.017	-0.024
					TBM-2	Check by Rover 2	329084.001	2359283.714	78.579	0.110	0.026	-0.002
					TBM-2	Check by Rover 3	329084.005	2359283.707	78.594	0.106	0.033	-0.017

Note: Client has confirmed that Lakhi Dam the FRL value(74.10 m) is from Mean Sea Level, TBM-1 RL value is shifted from FRL(Full Reservoir Level) of the Dam
Note: Base station was on Lakhi Dam TBM-1, TBM-1 value used to setup base (Fugro provided XYZ value), 3 reading taken for 2 sec each on TBM-2 by 3 rovers on pole mounted.

Prepared by Rambabu Sah

FUGRO

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 :	LAKHIGAM DAM	**LAKHI DAM TBM1**
	Observed By:	Pritam Seth,Atul Bhoyte	
	Date:	29/04/2021	

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

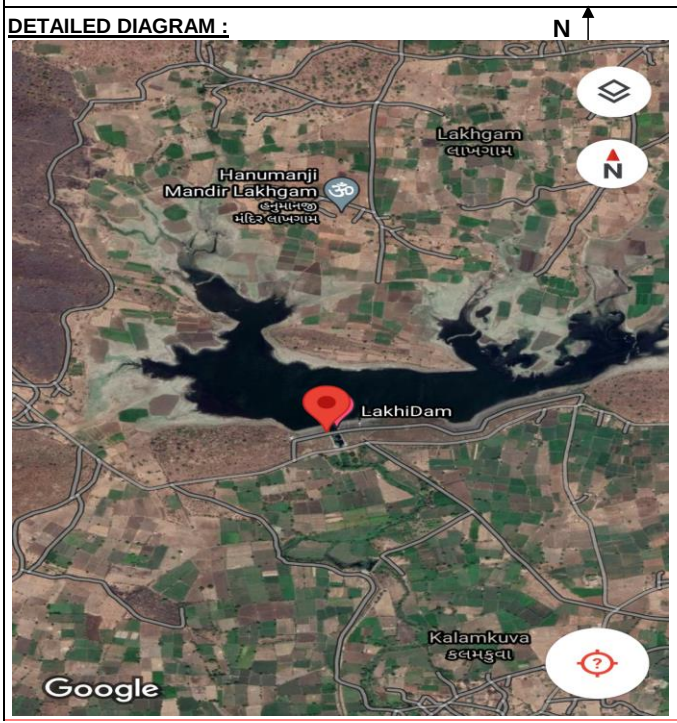
GEOGRAPHICAL COORDINATES:		**UTM COORDINATES:**		CM: 75° E
LATITUDE:	21°19'39.16142"N	EASTING:	3,29,114.621m E	σ = +/- 0.02 m
LONGITUDE :	073°21'08.25191"E	NORTHING:	23,59,292.459m N	σ = +/- 0.01 m
ELLIPSOIDAL HEIGHT:	19.282m Ell	CONVERGENCE :	-0.59942 Degrees	
HEIGHT ABOVE LAT/CD:	NA	TBM VALUE:	78.688 w.r.t MSL	

LOCATION & ACCESS : Its established in a left side concrete Piller towards West TOP OF DAM Road .Near steps.

STATION MARKING : LAKHI DAM TBM1 eastablised by Fugro. And point is marked with Yellow paint in a White concrete Piller.

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

Pritam Seth
Party chief (FSINPVT)

Deputy Executive Engineer
LAKHIGAM DAM
GOVT. OF GUJARAT

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 :	LAKHIGAM DAM	**LAKHI DAM TBM2**
Observed By:	Pritam Seth,Atul Bhoyte	
Date:	29/04/2021	

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

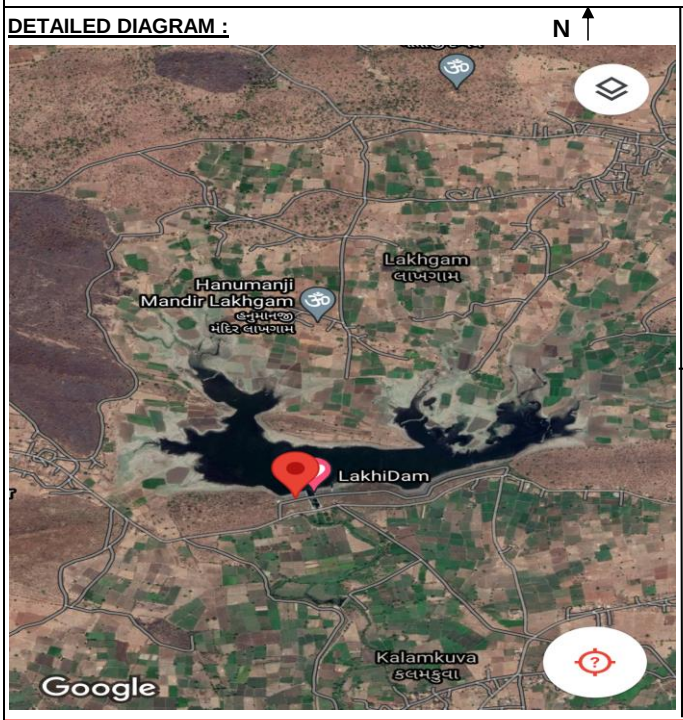
GEOGRAPHICAL COORDINATES:		**UTM COORDINATES:**		CM: 75° E
LATITUDE:	21°19'38.86756"N	EASTING:	3,29,084.111m E	σ = +/- 0.02 m
LONGITUDE :	073°21'07.19633"E	NORTHING:	23,59,283.740m N	σ = +/- 0.02 m
ELLIPSOIDAL HEIGHT:	19.278m	CONVERGENCE :	-0.59952 Degrees	
HEIGHT ABOVE LAT/CD:	NA	TBM VALUE:	78.577m w.r.t MSL	

LOCATION & ACCESS : Its established in a left side Concrete Piller towards west in TOP OF DAM Road.30m behind from Lakhi Dam TBM1.

STATION MARKING : LAKHI DAM TBM2 estabilised by Fugro. And point is marked with Yellow paint in a White Concrete Piller..

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

Pritam Seth
Party chief (FSINPVT)

Deputy Executive Engineer
LAKHIGAM DAM
GOVT. OF GUJARAT

RECORD OF LEVELLING

(To be used for levelling from an established HADAF DAM TBM1 to the Zero of ATG / Tide Pole)

Job No :	J-HYD-20-174630			Client Name :	Govt. of Gujarat
Levelling Equpt Used:	TOTAL STATION TRIMBLE S3			Equipment Serial/Asset No:	25-258398
Area/Location Name:	LAKHIGAM DAM			Date of Observation:	29/04/2021
Tide Guage Installed ?:	Yes, ATG PRESSURE SENSOR			Observer's Name:	Pritam Seth
ATG Zero setup at (m):	11.9		TBM Level at ATG Site	Prism Holder's Name:	Ganesh Sonawale

Start Point BM Name/ID:	**LAKHI DAM TBM1**		
Start Point BM Value (RL) (m):	**78.420**	FROM	**LAKHI DAM TBM 1**

End Point Level Name:	**TBM (ATG Setup)**		
End Point Level Value (m):	**168.526**	7.830	

TOP OF DAM TBM to ATG TBM (ATG Setup)

Station Name	Backsight(TOP OF DAM TBM)	Fore Sight(TBM ATG SETUP Point)
LAKHI DAM TBM1	78.42	78.095

TBM (ATG Setup) to TOP OF DAM TBM

Station Name	Backsight(ATG TBM)	Fore Sight(TOP OF DAM TBM)
LAKHI DAM TBM2	78.095	78.42

`

Misclosure =	0.000	meters	
Adjusted Tide Gauge Height =	**78.095**	meters	
Hence, the Zero of Tide Gauge is	**66.195**	**metres Above**	**MSL**

Checked by:Pritam Seth
Surveyor's Name:Pritam Seth
Date:29-04-2021

1.FRL Of LAKHI DAM IS 74.10 m above MSL. Old reference which has confirmed by CLIENT of Lakhigam Dam Govt. of Gujarat at site.
2. LAKHI DAM TBM1 and LAKHI DAM TBM2 established by Fugro.

Party Chief
Pritam Seth
FSINPVT

Deputy Executive Engineer
LAKHIGAM DAM
GOVT. OF GUJARAT

LEVELLING RECORD FROM FRL LAKHI DAM TO ALL TBM POINTS

Job No :	J-HYD-20-174630	Client Name :	GOVT. OF GUJARAT
Levelling Equpt Used:	AUTO LEVEL	Equipment Serial/Asset No:	256726
Area/Location Name:	LAKHIGAM DAM	Date of Observation:	30/04/2021
Observer's Name:	Pritam Seth	Staff Holder's Name:	Atul Bhoyte

TOP OF DAM TBM TO LAKHI DAM TBM1

BACK SIGHT	FORE SIGHT	RL Value	Point Name
		78.42	TOP OF DAM
1.413	1.145	78.688	LAKHI DAM TBM1
1.149	1.417	78.42	TOP OF DAM
Miscloser value	0		

LAKHI DAM TBM1 TO LAKHI DAM TBM2

BACK SIGHT	FORE SIGHT	RL Value	Point Name
		78.688	LAKHI DAM TBM1
1.07	1.181	78.577	LAKHI DAM TBM2
1.187	1.076	78.688	LAKHI DAM TBM1
Miscloser value	0		

TOP OF DAM TBM TO ATG

BACK SIGHT	FORE SIGHT	RL Value	Point Name
		78.42	TOP OF DAM
1.381	1.706	78.095	ATG
1.743	1.418	78.42	TOP OF DAM
Miscloser valu	0		

NOTE-

- FRL Value= **74.10m** w.r.t MSL which Provided and confirmed by Client at site.
- FRL to TOP of Dam TBM measured by Measuring Tape manually = 4.320. So, TOP OF DAM TBM= **78.420m**
- Lakhi Dam TBM1 and Lakhi Dam TBM2 established by Fugro for Topography purpose.ATG TBM used for Setup ATG and Mesure Daily Water Level.

PRITAM SETH
PARTY CHIEF
FSINPVT

Deputy Executive Engineer
LAKHIGAM DAM
GOVT. OF GUJARAT

Appendix F

List of Charts

(1 page)

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	**This Document**
5	Final Report on Survey	1 week from receipt of client's comments	10	Will be submitted after receiving client's comment

Details of Charts Accompanying this Report

Details of Charts							
Sl. No.	Charts showing Results of Bathymetry and Topography Survey at Lakhigam Reservoir	Sheet No.	Encl. No.	Drawing No.: JHYD-20-174630/WRD/GUJARAT/BS/	Rev. No	HS	VS
1	Reservoir Bed and Topographic Heights	01 of 01	01 of 03	B/01/9629	0	1:2000	-
2	Contour Map of Lakhigam Reservoir	01 of 01	02 of 03	B/01/9703	0	1:2000	-
3	Shaded Relief Image Prepared from SBES Data	01 of 01	03 of 03	I/01/9704	0	1:2000	-
Details of Other Deliverables							
1	L-section	Soft copy					
2	C-section at every 100 m	Soft copy					