REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF PUBLIC WORKS
AND HIGHWAYS

REPUBLIC OF THE PHILIPPINES

PREPARATORY SURVEY FOR FLOOD RISK MANAGEMENT PROJECT FOR CAGAYAN DE ORO RIVER (FRIMP-CDOR)

FINAL REPORT

VOLUME - III
SUPPORTING REPORT (I)

MARCH 2014

JAPAN INTERNATIONAL COOPERATION AGENCY

NIPPON KOEI CO., LTD.
CTI Engineering International Co., Ltd.
PASCO Corporation

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List of Reports

Exchange Rate

US Dollar (US$) 1.00 = Philippine Pesos (PHP) 42.85 = Japanese Yen (Y) 97.43

(1 Philippine Peso = 2.274 Japanese Yen)

（as of July 2013）

Abbreviations / Acronyms

1D	One-dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACEL	Association of Carriers and Equipment Lessors, Inc.
ACI	American Concrete Institute
AD	Ancestral Domain
A&D	Alienable and Disposable area
ADB	Asian Development Bank
AfD	Agence française de développement (French Development Agency)
AFP	Armed Force of Philippines
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALOS	Advanced Land Observing Satellite
AMSL	Above Mean Sea Level
ANR	Assisted Natural Regeneration
AO	Administrative Order
ARG	Automatic Rain Gauge
ARMM	Autonomous Region in Muslim Mindanao
ASTM	American Society for Testing and Materials
AusAid	Australian Agency for International Development)
AWS	Automatic Warning System
BC Ratio	Benefit-Cost Ratio
BENRO	Bukidnon Environment and Natural Resource Office
BDRRMC	Barangay Disaster Risk Reduction and Management Council
BFAR, DA	Bureau of Fisheries and Aquatic Resources, DA
BH	Borehole
BOC, DPWH	Bureau of Construction, DPWH
BOD	Biochemical Oxygen Demand
BOD, DPWH	Bureau of Design, DPWH
BOM, DPWH	Bureau of Maintenance, DPWH
BP	Before Present
BS	British Standard
BSWM	Bureau of Soils and Water Management, DA
BWPDC	Bukidnon Watershed Protection and Development Council
BWRBF	Bukidnon Watershed and River Basin Forum
CAP	Comprehensive Action Plan
CARI	Contractor's All Risk Insurance
CATDDO	Catastrophe Deferred Drawdown Option
CBEWS	Community-Based Early Warning System
CBFEWS	Community Based Flood Early Warning System
CBFMA	Community-Based Forest Management Agreement
CCA	Climate Change Adaptation
CDIA	Cities Development Initiative for Asia, ADB
CDO	Cagayan de Oro
CDOR	Cagayan de Oro River
CDORBMC	Cagayan de Oro River Basin Management Council
CDP	Comprehensive Development Plan
CDRRMC	City Disaster Risk Reduction and Management Council
CENRO, DENR	Community Environment and Natural Resources Office, DENR
CEPALCO	Cagayan Electric Power and Light Company, Inc.
CGIAR-CSI	Consortium for Spatial Information of the Consultative Group on International Agricultural Research
CHED	Commission on Higher Education
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLENRO,	City Local Environment and Natural Resource Office, LGU
CLUP	Comprehensive Land Use Plan

CO	Central Office
COA	Commission on Audit
COCICM-TWGPMET	Cagayan de Oro City Integrated Coastal Management – Technical Working Group and Project Monitoring and Evaluation Team
COWD	Cagayan de Oro Water District
CPDO	City Planning and Development Office
CPI	Consumer Price Index
CPR	Cardiopulmonary Resuscitation
CRM	Coastal Resources Management
CRMP	Coastal Resources Management Plan
CSCAND	Collective Strengthening of Community Awareness for Natural Disaster
CSO	Civil Society Organization
CU	Consolidated Undrained
C/V	Calibrated / Validated
CY	Calendar Year
DA	Department of Agriculture
DANA	Damage Assessment & Needs Analysis
DAO	Department Administrative Order
DBM	Department of Budget and Management
DCC	Disaster Coordinating Council
DD	Detailed Design
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
Dep ED	Department of Education
DFA	Department of Foreign Affair
DF/R	Draft Final Report
DHWL	Design High Water Level
DILG	Department of Interior and Local Government
DND	Department National Defense
DO / D.O.	Department Order
DO	Dissolved Oxygen
DOE	Department of Energy
DOF	Department of Finance
DOH	Department of Health
DOJ	Department of Justice
DOLE	Department of Labor and Employment
DOST	Department of Science and Technology
DOT	Department of Tourism
DOTC	Department of Transportation and Communication
DP/R	Draft Progress Report
DPWH	Department of Public Works and Highways
DRM	Disaster Risk Management
DRRM	Disaster Risk Reduction Management
DRRMC	Disaster Risk Reduction and Management Committee
DSWD	Department of Social Welfare and Development
DTI	Department of Trade and Industry
DTM	Digital Terrain Model
DUPA	Detailed Unit Price Analysis
ECA	Environmentally Critical Areas
ECC	Environmental Compliance Certificate
ECP	Environmentally Critical Project
EIA	Environmental Impact Assessment
EIAPO	Environmental Impact Assessment Project Office
EIRR	Economic Internal Rate of Return
EIS	Environmental Impact Statement
EISS	Environmental Impact Statement System
EL	Elevation
EMB, DENR	Environmental Management Bureau, DENR

EMD	Estate Management Division, LGU
EMoP	Environmental Monitoring Plans
ENCA	The Project for Enhancement of Capabilities in Flood Control and Sabo Engineering of the Department of Public Works and Highways
ENPV	Economic Net Present Value
ENRO	Environment and Natural Resource Office, LGU
EO	Engineering Office
EO	Executive Order
EP	Exploration Permit
EPRMP	Environmental Performance Report and Management Plan
ERDS, DENR	Ecosystems Research and Development Service, DENR
ESSO, DPWH	Environmental and Social Services Office, DPWH
EU	European Union
FCSEC, DPWH	Flood Mitigation and Sabo Engineering Center, DPWH
FEWC	Flood Early Warning Center
FEWS	Flood Early Warning System
FFWS	Flood Forecasting and Warning System
FIRR	Financial Internal Rate of Return
FMB, DENR	Forest Management Bureau, DENR
FMC	Flood Mitigation Committee
FMS, DENR	Forest Management Service, DENR
F/R	Final Report
FRIMP-CDOR	The Preparatory Survey for Flood Risk Management Project for Cagayan de Oro River
F/S	Feasibility Study
FWL	Flood Water Level
GDP	Gross Domestic Products
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
GOJ	Government of Japan
GOP	Government of the Philippines
GPS	Global Positioning System
GRDP	Gross Regional Domestic Products
GSIS	Government Service Insurance System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
HEC-RAS	Hydrologic Engineering Center River Analysis System
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome
HLURB	Housing and Land Use Regulatory Board
HUDCC	Housing and Urban Development Coordinating Council
HVCC	High Value Commercial Crop
ICC	Indigenous Cultural Community
ICC	Investment Coordination Committee
IC/R	Inception Report
ICS	Incident Command System
IDP	Internally Displaced Person
IEC	Information, Education and Communication
IEE	Initial Environmental Examination
IEEC	Initial Environmental Examination Checklist
IEER	Initial Environmental Examination Report
IFMA	Industrial Forest Management Agreement
INREM	Integrated Natural Resources and Environmental Management
IP	Indigenous People
I/P	Implementation Program
IRBMDMP	Integrated River Basin Management and Development Master Plan
IRR	Implementing Rules and Regulations
IT/R	Interim Report

IUCN	International Union for Conservation of Nature and Natural Resources
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
JIS	Japanese Industrial Standards
LCP	League of Cities of the Philippines
LDRRMC	Local Disaster Risk Reduction and Management Council
LDRRMF	Local Disaster Risk Reduction and Management Fund
LGU	Local Government Unit
LIAC	Local-Inter Agency Committee
LIDAR	Light Detection and Ranging、Laser Imaging Detection and Ranging
LMP	League of Municipalities of the Philippines
LNB	*Liga Ng mga* Barangay (League of Barangays of the Philippines)
LP	Laser Profile
LPP	League of Provinces of the Philippines
LSB	Local Special Body
MBDA	Macahalar Bay Development Alliance
MCL	Maximum Contamination Level
MDRRMC	Municipal Disaster Risk Reduction Management Council
MENRO	Municipal Environment and Natural Resource Office, LGU
MFC&DP	Major Flood Control & Drainage Project
MFCDP-II	Major Flood Control and Drainage Project – Cluster II
MFL	Maximum Flood Level
MGB, DENR	Mines and Geosciences Bureau, DENR
MinDA	Mindanao Development Authority
MKRNP	Mt. Kitanglad Range Natural Park
MLLW	Mean Lower Low Water
MLLWL	Mean Lowest Low Water Level
MMC	McKeough Marine Center
MOA	Memorandum of Agreement
M/P	Master Plan
MPDO	Municipal Planning and Development Office
MSL	Mean Sea Level
MTSAT	Multi-functional Transport Satellite
MWSS	Metropolitan Waterworks and Sewerage System
NAMRIA	National Mapping and Resources Information Authority
NAPC-VDC	National Anti-Poverty Commission- Victims of Disasters and Calamities
NBCP	National Building Code of the Philippines
NCIP	National Commission on Indigenous Peoples
NCRFW	National Commission on the Role of *Filipino* Women
NDCC	National Disaster Coordinating Council
NDRRMC	National Disaster Risk Reduction and Management Council
NDRRMF	National Disaster Risk Reduction and Management Fund
NEDA	National Economic Development Agency
NFMO	National Flood Mitigation Office
NGA	National Government Agency
NGO	Non-Government Organization
NGP	National Greening Program
NHA	National Housing Authority
NIA	National Irrigation Administration
NIPAS	National Integrated Protected Areas System
NOAA	National Oceanic and Atmospheric Administration - Satellites
NOAH	Nationwide Operational Assessment of Hazards
NON-ECA	Non-Environmentally Critical Area
NON-ECP / NECP	Non-Environmentally Critical Project
NORMECA	Northern Mindanao Electric Cooperatives Association
NPAA	Network of Protected Areas for Agriculture
NPC	National Power Corporation
NSCB	National Statistical Coordinating Board

NSO	National Statistics Office
NWRB	National Water Resources Board
NWRMO	National Water Resources Management Office
OCD	Office of Civil Defense
O&M	Operation and Maintenance
OPACC	Office of the Presidential Adviser on Climate Change
OPAPP	Office of the Presidential Adviser on Peace Process
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PAWCZMS, DENR	Protected Areas, Wildlife and Coastal Zone Management Services, DENR
PAWB, DENR	Protected Areas and Wildlife Bureau, DENR
PC	Precast
PCBARMA	Protected Area Community-based Forest Management Agreement
PCDG	Prestressed Concrete Deck Girder
PCG	Philippine Coast Guard
PD	Presidential Decree
PDO	Planning and Development Office
PDR	Project Description Report
PDRRMC	Provincial Disaster Rick Reduction Management Council
PEISS	Philippine Environmental Impact Statement System
PENRO, DENR	Provincial Environment and Natural Resources Office, DENR
PEPRMP	Programmatic Environmental Performance Report and Management Plan
PES	Payment of Environmental Services
PFS	Prefeasibility Study
PhilHealth	Philippine Health Insurance Corporation
PHIVOLCS	Philippine Institute of Volcanology and Seismology
PIA	Philippine Information Agency
PM	Particular Matter
PMO	Project Management Office
PMO	Presidential Memorandum Order
PNP	Philippine National Police
PNRC	Philippine National Red Cross
PO	People’s Organization
PP	Presidential Proclamation
PPA	Philippine Ports Authority
PPP	Public-Private Partnership
P/R	Progress Report
PRC	Philippine Red Cross
PSGC	Philippine Standard Geographic Code
PTM	Philippine Traverse Mercator
QRF	Quick Response Fund
RA	Republic Act
RAP	Resettlement Action Plan
RBCO	River Basin Control Office, DENR
RBO	River Basin Organization
RC	Reinforced Concrete
RDC	Regional Development Council
RDRRMC	Regional Disaster Reduction Management Council
RED	Regional Executive Director
REDAS	Rapid Earthquake Damage Assessment System
RIDF	Rainfall Intensity Duration Frequency
ROW	Right of Way
ROWA	Right of Way Acquisition
RR	Rainfall-Runoff
SALT	Sloping Agricultural Land Technology
SAPA	Special Agreement in Protected Areas
SCF	Standard Conversion Factor
SDR	Social Discount Rate

SEA	Strategic Environmental Assessment
SIFMA	Socialized Industrial Forest Management Agreement
SPT	Standard Penetration Test
SRLSF	Safer River,. Life Saver Foundation, Inc
SRTM	Shuttle Radar Topography Mission
SSS	Social Security System
Sta.	Station
TA	Technical Assistance
TAC	Technical Advisory Committee
TDS	Total Dissolved Solid
TIN	Triangulated Irregular Network
TOR	Terms of Reference
TS	Tropical Storm
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
TTS	Telegraphic Transfer Selling
TUREDECO	Turbines Resource and Development Corporation
TWG	Technical Working Group
TY	Typhoon
ULAP	Union of Local Authorities of the Philippines
UNDP	United Nations Development Programme
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USLE	Universal Soil Loss Equation
UU	Unconsolidated Undrained
VAT	Value Added Tax
WB	World Bank
WL	Water Level

Measurement Unit

Extent

km^2	square-kilometer (1.0 km x 1.0 km)
ha	10,000 square-meter (100 m x 100 m)
acre	

Length

mm	millimeter
cm	centimeter (10 mm)
m	meter (100 cm)
km	kilometer (1,000 m)
l.m	linier meter

Currency

US$	United State Dollars
PHP	Philippine Pesos

Number

million	10^6
billion	10^9

Temperature

°C	Degree Celsius

Volume

m^3	cubic-meter
l	litter
Ncm / NCM	Normal Cubic Meter
MCM	Million Cubic Meters

Weight

g	gram
kg	kilogram (1,000 g)
ton	metric ton (1,000 kg)
mg	milligram (10^{-3} g)
µg	microgram (10^{-6} g)

Time

sec	second
min	minute (60 sec.)
hr	hour (60 min.)
yr	year
Ma	Mega annum (10^6 years)

Others

dB (A)	decibel
kN/m^2	kilonewtion per square-meter
d/s	down stream

Supporting Report
Appendix A
Topographic and River Surveys

PREPARATORY SURVEY
FOR
FLOOD RISK MANAGEMENT PROJECT
FOR
CAGAYAN DE ORO RIVER (FRIMP-CDOR)
IN
THE REPUBLIC OF THE PHILIPPINES

FINAL REPORT

VOLUME III SUPPORTING REPORT (I)

Appendix A

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CHAPTER 1 GENERAL OF SURVEY WORKS

1.1 Survey Objectives and Scope of Works

Topographical and river surveys were conducted respectively to produce grid data showing terrain surface and to draw up river profile and cross section for the river stretch from river mouth to 14 km upstream along the Cagayan de Oro River.

The surveys are composed of the following three(3) works of which 1) and 2) were taken by single LiDAR survey system simultaneously.

1) Airborne LiDAR survey
2) Digital aerial photography and ortho imagery production
3) River profile and cross section survey

1.2 Survey Area

1) Topographical survey (scale of 1/1,000) : 40km^2 in the most downstream area
2) Topographical survey (scale of 1/10,000) : 1,500 km^2 of the whole river basin.
3) River survey : River stretch from river mouth to upstream for 14 km.

1.3 Work Component of the Surveys

Each survey was conducted with following work components respectively. The additional survey was executed to make up for a malfunction of LiDAR survey system.

(1) Airborne LiDAR Survey

1) Flight and surveying plan
2) GPS base station placement
3) Ground control points placement
4) Surveying
5) 3D surveyed data, Original data production
6) Ground data production
7) Grid data production
8) Contour data production

The following works were supplementally conducted because of malfunction of air borne LiDAR survey system.

9) Aerial triangulation
10) Digital mapping

(2) Digital Aerial Photography and Ortho Imagery Production

1) Aerial photography
2) Ortho imagery production

(3) River Profile and Cross Section Survey

1) Bench mark placement
2) Vertical reference point Exploration
3) River center and profile survey
4) River cross section survey
5) Inspection

1.4 Technical Specification of the Work

(1) Product Specification

1) Pulse density of Airborne LiDAR survey: more than 1 points into 2m×2m
2) Side length of Grid : 2m
3) Resolution for Ortho Imagery : 50cm
4) Interval of river cross section : every 500m and sections at 5 bridges
5) Aerial triangulation (supplementary works)
   Standard deviation for GCP on : less than 0.5m

(2) Technical Reference

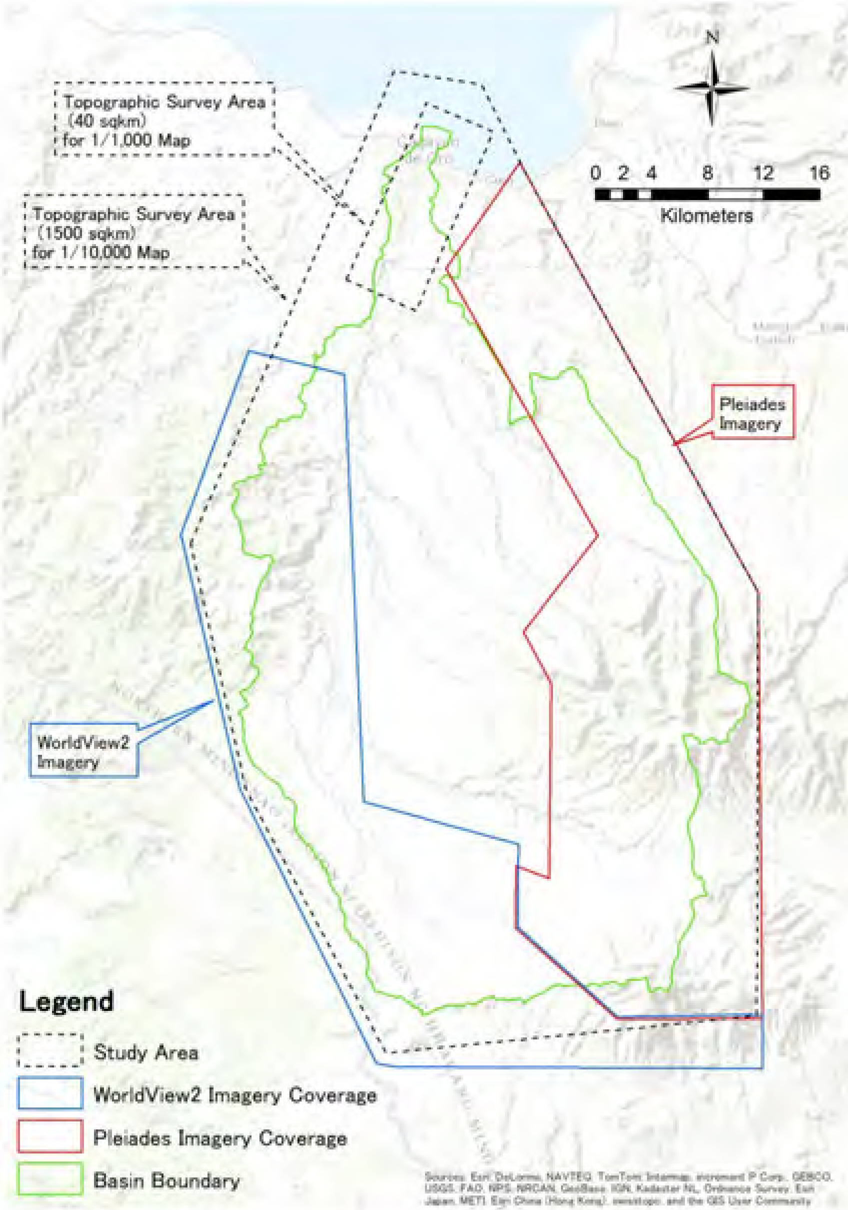
Standard for Public Survey Works, Notification No.413 of Japan, Monistry of Land, Infrastructure, Transport and Tourism on 31st March, 2008.

1.5 Data and Reference Materials

The following materials have been collected for reference from NAMRIA and related agencies.

1) Digital topographic map of scale 1/50,000
2) Ortho imagery of scale 1/50,000
3) Orthophotomap of scale 1/10,000
4) Satellite imagery by World View 2
5) Satellite imagery by Pleiades

The specification of the materials above is specified in Appendix A Figure 1.5.1 shows the coverage area of the collected satellite imageries.



Source : JICA Survey Team

Figure 1.5.1 Coverage Area of the Available Satellite Imagery

CHAPTER 2 INVESTIGATION OF MEAN SEA LEVEL(MSL)

2.1 Mean Sea Level at Macabalan Wharf

The mean sea level for vertical reference in Cagayan de Oro was investigated in order to settle the vertical origin for the Survey because the height system of projective method in the Philippines adopts MSL (mean sea level) method.

The Survey Team collected and examined the tidal data as reference sea level of Cagayan de Oro.

(1) Collection of Tidal Data

The tidal data for 51 months between 2007 and 2012 was provided by NAMRIA as shown in Table 3.2.1.

(2) Methodology to Convert the Tidal Data into the Mean Sea Level.

It was confirmed that NAMRIA used 'Tidal Analysis and Prediction Software of Flinders University Australia' to derive MSL, which is the same method as employed in Tokyo Bay.

1) Mean level of monthly high tide in every year：$F=\Sigma f / n$

2) Mean level of monthly low tide in every year：$E=\Sigma e / n$

3) Mean sea level in every year：$M = F+E / 2$

4) Mean sea level in whole examination period：$M' = \Sigma M / n$

(f＝level of high tide、e ＝ level of low tide、n = frequency)

Table2.1.1 Tidal Data at Macabalan Wharf

MEAN SEA LEVEL																	
CAGAYAN DE ORO																	
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	FOR YEAR		TOTAL		MONTHS
	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	m.	SUM	MEAN	SUM	MEAN	
2007											2.49	2.43	4.914	2.457	4.914	2.457	2
2008	2.41	2.45	2.51	2.52	2.57	2.54	2.57	2.57	2.58	2.51	2.49	2.48	30.200	2.517	35.114	2.508	14
2009						2.54	2.53	2.53	2.54	2.49	2.41	2.33	17.370	2.481	52.484	2.499	21
2010	2.29	2.28	2.30	2.35	2.43	2.50	2.55	2.57					19.270	2.409	71.754	2.474	29
2011			2.47	2.46	2.50	2.51	2.50	2.51	2.53	2.52	2.50	2.50	24.990	2.500	96.753	2.481	39
2012	2.44	2.49	2.53	2.51	2.55	2.56	2.56	2.54	2.60	2.55	2.46	2.46	30.232	2.519	126.985	2.490	51

Source : NAMRIA

(3) Mean Sea Level (MSL) at Macabalan Wharf（ref. to Figure 2.1.1）

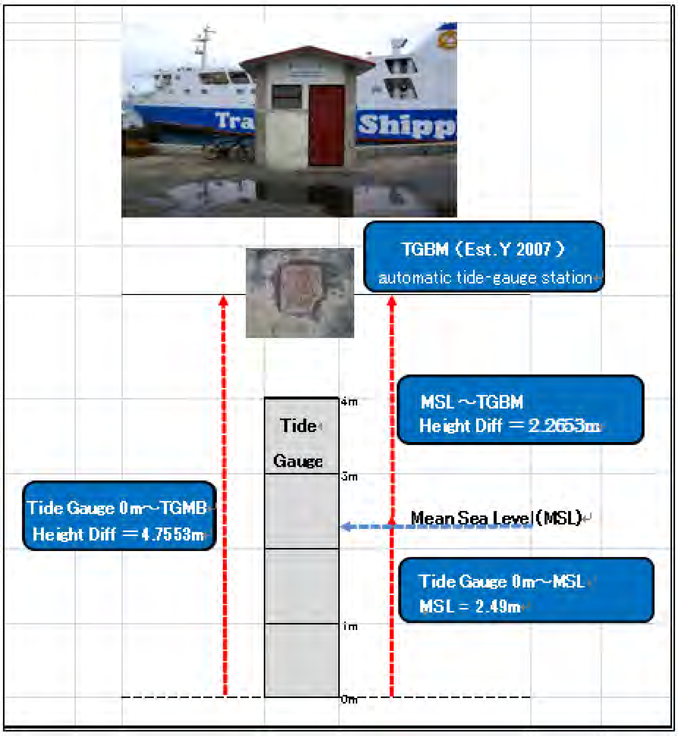
1) Mean sea level at Macabalan wharf = +2.49m

(height from bottom of tidal gauge to MSL）

2) The height of TGBM = +4.7553m

(height from bottom of tidal gauge to the top of tidal post）

3) The height between MSL to the top of tidal gauge） = 2.2653m



Source : JICA Survey Team

Figure 2.1.1 Mean Sea Level at Macabalan Wharf

2.2 Inspection for Bench Marks in Cagayan de Oro

(1) Survey of Bench Marks

The inspection survey was conducted on TGBM (reference bench mark) and BM-5 which were used for the topographical survey. Other bench marks named such as MSE-100 and MSE-110 in Cagayan de Oro City also surveyed for reference. The result is presented in Table 2.2.1

Table 2.2.1 Result of the Inspection Survey on Bench Marks in Cagayan de Oro City

Station Name	Surveyed by NAMRIA(i) Elevation(m) (i)	Surveyed by Survey Team (ii) Elevation(m) (ii)	Difference between (i) and (ii) (m) (iii) = (ii) – (i)	Remarks
TGBM(NAMRIA)	2.265	2.265	0.000	(1)
BM 5(NAMRIA)	2.068	2.106	0.038	(1)
MSE 100	4.871	4.728	-0.143	(2)
MSE 110	5.762	5.623	-0.139	(2)

Remarks: (1) Elevation from MSL of Macabalan Wharf of Cagayan de Oro City Tide Gauge Station; Surveyed by the Hydrography Department, NAMRIA

(2) Elevation from MSL of Surigao City Tide Gauge Station; Surveyed by the Mapping and Geodesy Department, NAMRIA

Source : JICA Survey Team

(2) Confirmation of Reference Sea Level

The level heights of MSE 100 and MSE 110 as shown in Table 2.2.1 (i) are based on the MSL of Surigao City Tide Gauge Station. On the other hand, TGBM and BM-5 are based on the MSL of Macabalan Wharf of Cagayan de Oro City Tide Gauge Station. The difference of both heights is about 0.14m.

(3) Vertical Origin for Survey

According to the inspection conducted by the Survey Team, it is concluded that TGBM is to be used as the vertical origin for the Survey which was revised in 2011. However it is noted that TGBM has existed thereat since before 2011 and the previous height of TGBM(named as TGBM-2007) is different from the current TGBM.

CHAPTER 3 TOPOGRAPHICAL SURVEY

3.1 Scope of Survey

Topographical survey consists of the Airborne LiDAR survey and the digital aerial photography. Producing grid data in the project area and taking aerial imagery of real terrain surface are the objectives of the topographical survey.

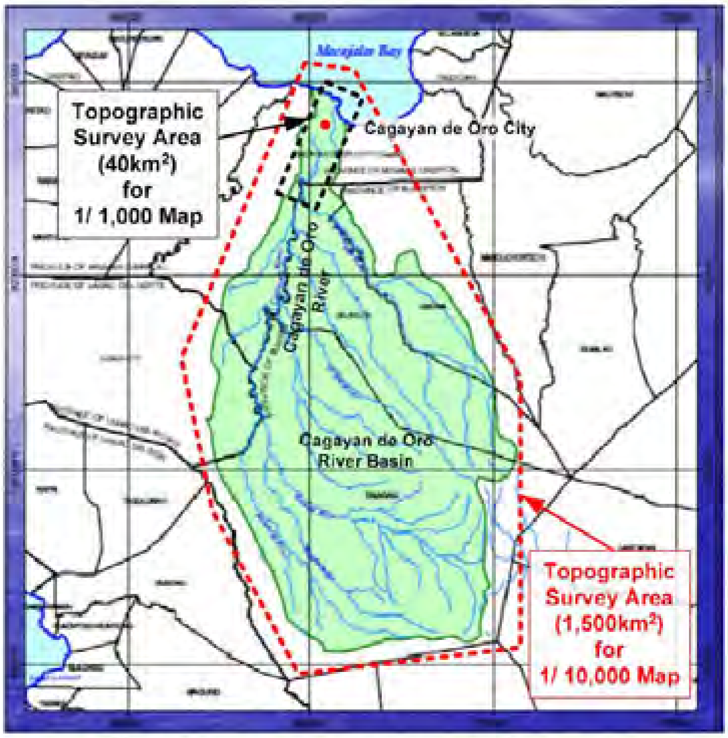
3.1.1 Objective Area

The Airborne LiDAR survey was conducted to obtain topographic data for the hydraulic analyses. It was implemented to produce: topographic data at a scale of 1/10,000 covering 1,500 km^2 in the Cagayan De Oro River basin; and orthophotomaps at a scale of 1/1,000 covering 40 km^2 from the river mouth of the Cagayan De Oro River extending 14 km upstream along the river.

The Airborne LiDAR survey consists of the following works:

1) Preparation of digital topographic maps at a scale of 1/10,000 with a contour line interval of 2 meters. The coverage of the survey is along the Cagayan De Oro River basin and surrounding areas with a total area of about 1,500 km2.
2) Preparation of orthophotomaps at a scale of 1/10,000 with a contour line interval of two(2)m. The areas to be covered are the same as mentioned in (i).
3) Preparation of orthophotomaps at a scale of 1/1,000 with a contour line interval of one(1) meter. The area to be cover has a 40 km^2 area from the river mouth of the Cagayan De Oro River extending 14 km upstream along the river.

Figure 3.1.1 shows work area of the survey and the plan for both survey are shown below:



Source: NAMRIA, F/S2011

Figure 3.1.1Project Area（Maps of 1/1,000 and 1/10,000）

3.1.2 Planning of Airborne LiDAR Survey and Digital Aerial Photography

- System : ALS-50Ⅱ
- Camera : RCD105
- Calculated Point Density : 1.7 points / m^2 （1/1,000）
  0.4 points / m^2 （1/10,000）
- Field Of View : 60°
- Above Ground Level : 800m
- Side Lap LiDAR : 30%
- Side Lap Images : 35%
- Front Lap Images : 60%
- Total Flight Line : 239 Lines
- GPS Base Station : 1 station
- GCP's : 64Points

The projective method employed the WGS84/UTM51N and EGM96 orthometric elevations. （Note：River survey used PTM, MSL）

3.1.3 Flight Performance

(1) Airborne LiDAR Survey in the First Year

During flight standby period between December 2012 and April 2013, available flight days for obtaining the imagery was 5 days only. The Airborne LiDAR survey encountered substantial data missing by system RIEGL in around river mouth area although no improper use of system was confirmed. Data of Airborne LiDAR survey obtained during the said period were not used for the final products. However, ortho imagery taken by auxiliary camera were judged available for 917 km^2 as basic information for the analyses.

(2) Airborne LiDAR Survey in the Second Year

The survey in the second year was conducted starting from the early December 2013 and completed by January 3, 2014 by employment of LICA's ALS50-II system.

<u>Survey for 1/1,000(40km^2)</u>

3-hours flight on December 17, 2013; completed

<u>Survey for 1/10,000 (1,500km^2)</u>

2.5-hours flight on December 20, 2013; 25 % accomplished

3.75-hours flight on December 21, 2013; 55 % accomplished

3.0-hours flight on December 22, 2013; 70 % accomplished

3.0-hours flight on December 28, 2013; 85 % accomplished

3.0-hours flight on December 30, 2013; 100 % accomplished

2.0-hours flight on January 03, 2014; re-survey for a part of the area

3.1.4 LiDAR Survey Result

(1) Accuracy of Coordination

Standard deviation of the LiDAR survey results in elevation with GCP's was confirmed to be within the criteria of 0.1 m or lower in terms of the standard deviation

Table 3.2.3 Absolute Accuracy of Elevation of LiDAR Points

Average of elevation difference (AVG dZ)	-0.014 m
Minimum elevation difference (-) (MIN dZ)	-0.234 m
Minimum elevation difference (+) (MIN dZ)	+0.217 m
Root mean square (RMS)	+0.093 m
Standard deviation (STDEV)	+0.093 m

Source: JICA Survey Team

Source: JICA Survey Team

Figure 3.1.2 GCP Locations

(Yelllow points)

(2) Imagery Sharpness

Any one shot of imagery was not covered by cloud 10% or more that clearness of imagery was assured for 1,500km^2.

3.1.5 Topographic Map Production

(1) Topographic Map for Scale 1/1,000

The topographic map for scale of 1/1,000 is prepared in ortho-photomap image, which preparation needs contour data and ortho imagery. However, insufficient number of data had been available in the area of 25 km^2 before when additional survey was conducted. As an alternative method, the aerial triangulation and digital mapping were adopted.

(2) Topographic Map for Scale 1/10,000

It is necessary for preparation of the topographic map of scale 1/10,000 that topographic objects are digitized from ortho imagery and combined with contour lines from the LiDAR data in area of 1,500km^2. A field ground survey has been conducted during the additional GCP survey to obtain necessary information to be included in the topographical map.

(3) Contour Lines for 1/10,000

Contour lines for topographic map of 1/10,000 were produced from ground data through TIN data (triangulated irregular network).

3.2 Additional and Correction Survey

(1) Addition of Ground Control Point(GCP)

The additional GCP arrangement was conducted for 11 points as shown in Figure 3.2.1in July 2013 to keep accuracy of product, because additional and additional GCP will be effectual as described below.

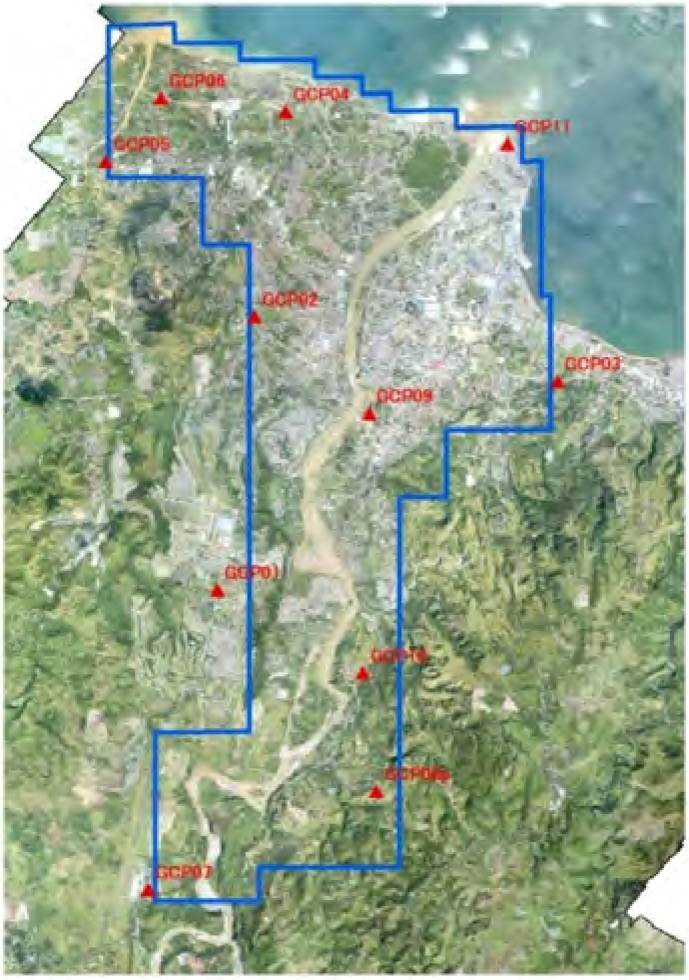
(2) Aerial Triangulation

Point density, as described in Section 1.4, should be more than 1 point into 2.0m×2.0m which is equivalent to cartographic information level 2500, as stated in article 275 in the Standard for Public Survey Works (refer to 1.4 (2)).

The standard deviation of the aerial triangulation was 0.397m as shown in Table 3.2.1 which is within 0.5m as stated as a requirement in article 172 in the standard. There is another requirement for aerial imagery, which is stated in article 253, that standard deviation error should be less than 0.5m as for cartography information level 1000. The result of this aerial triangulation could be concluded be enough for ortho imagery production.

Table 3.2.1 Result of Aerial Triangulation (Standard deviation to GCP's)

GCP	Field Survey			Observation on AT			Difference		
	X	Y	H	X	Y	H	DX	DY	DH
GCP01	678558.498	934117.022	119.023	678558.592	934117.211	118.923	-0.094	-0.189	0.100
GCP02	679116.525	938185.412	9.16	679116.376	938185.701	9.058	0.149	-0.289	0.102
GCP03	683623.993	937214.066	13.334	683624.053	937213.99	13.496	-0.060	0.076	-0.162
GCP04	679581.902	941230.734	2.225	679582.012	941230.442	2.356	-0.110	0.292	-0.131
GCP05	676903.736	940491.008	2.846	676903.613	940490.89	2.896	0.123	0.118	-0.050
GCP06	677727.389	941423.849	2.685	677727.196	941424.013	1.861	0.193	-0.164	0.824
GCP07	677532.346	929671.443	180.24	677532.32	929671.403	179.949	0.026	0.040	0.291
GCP09	680821.894	936741.179	4.581	680821.961	936741.259	5.394	-0.067	-0.080	-0.813
GCP10	680731.134	932886.791	66.064	680731.146	932886.85	66.337	-0.012	-0.059	-0.273
GCP11	682885.595	940746.464	1.739	682885.227	940746.115	1.619	0.368	0.349	0.120
Standard deviation									0.397



Source : JICA Survey Team

Figure 3.2.1 GCP Location (Red Points) and DEM Coverage (Blue polygon, 40km^2)

(3) Contour Line Mapping

Based on the result of the aerial triangulation, mapping was undertaken as shown in Figure 3.2.2 incorporating the result of river survey to cope with difficulty in mapping on low lying area.

Source : JICA Survey Team

Figure 3.2.2 Contour Lines and River Cross Section Line

(4) DEM Deneration, Evaluation and Adjustment

DEM can be generated automatically based on the contour lines obtained, In case DEM is inconsistent to the result of river survey or flood analysis, the contour line should be re-drawn to improve DEM which is generated as secondary data of the contour. There is no article about standard deviation between DEM and real terrain surface in Standard for Public Survey Work. With an adjustment of DEM, the standard deviation has been improved that the standard deviation is 1.884m for any 268 points and 0.931 for any 223 points in downstream 10km area.

Contour Lines

DEM Data

Source : JICA Survey Team

Figure 3.2.3 1/1,000 Contour Lines and DEM Data

3.3 Final Products

(1) Original Data and Ground Data

The ground data were attained in conformity with the standard through filtering procedure of the original data as shown below:

1) Area for scale 1/1,000

		Plan	Actual
Survey Area	:	40.0km^2	40.0km^2
Points Density	:	1.7 points / m^2	2.6 points / m^2

2) Area for scale 1/10,000

		Plan	Actual
Survey Area	:	1,500 km^2	1,500 km^2
Points Density	:	0.4 points / m^2	0.6 points / m^2

(2) Grid Data

Grid data formed of 2m x 2m mesh were produced from the ground data. Production was made by applying interpolation incorporating terrain variation.

(3) Ortho Imagery

Complete ortho imageries for whole 1,500km^2 area have been secured in the second year survey so that the final products contains only the said imageries without using the ortho imageries partially obtained in the first year survey.

(4) Topographic Map

Topographic map is produced with map digitizing method following Standard for survey works.

- Planimetric features are digitized provided that the said feature is more than 1mm on orthophoto images which is equivalent to 1m on 1/1,000 map and 10m on 1/10,000 map respectively.
- Field survey was not carried out aiming at correction of planimetric features.
- Polygon shape is formed so as to pick up planimetric features in flood analysis.

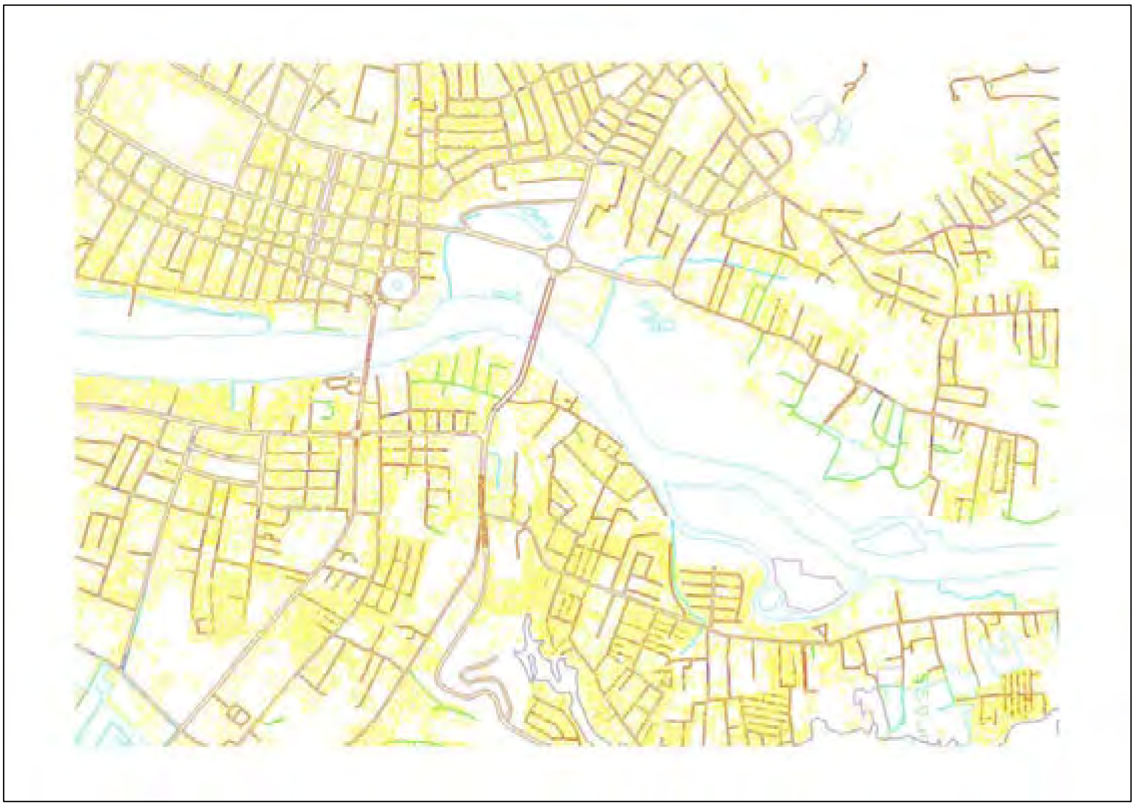
The rule of data acquisition is as presented in Table 3.3.1.

Table 3.3.1 Data Acquisition Rule for Planimetric Features

	Digitized	Not Digitized
Acquisition	・Objects seen on the ortho images ・Famous public facilities	・Objects to be found by field survey ・Administrative boundary such as Barangay boundary
1/1,000	Road, Stairs, Road divider, House, Building, Park, Sports Ground, Pool, River, Pond, Dam, Reservoir, Pier, Breakwater, Contour, Vegetation,	Road type, Road facilities (Traffic sign, Pole), Gate, Statue, Electric Line, River type, Wave dissipating, Covering, Land usage, Side slope
1/10,000	Road, House, Park, Sports Ground, Pool, River, Pond, Dam, Reservoir, Breakwater, Contour, Vegetation, Pier,	Stairs, Road divider, House type,
Note	Polygon shape for town block, park	House boundary, Margin design

(5) Orthophoto Map

Images of orthophoto maps containing the data to be acquired as shown in Table 3.3.1 are presented in Figure 3.3.1



1/10,000Map

1/1,000Map

Source : JICA Survey Team

Figure 3.3.1 Image of Orthophoto Map

CHAPTER 4 RIVER SURVEY

4.1 Work Plan and Output

The objectives of the River Survey is to obtain the river profile and cross section data to be used in the hydraulic analysis and structure design.

(1) General

The projection for river survey is as follows:

Plane coordinates : PTM（Philippines Transverse Mercator）

Elevation coordinates : MSL（Mean Sea Level）

The output of the river survey was made with the said projection which is different from that for the topographical survey. Data adjustment in terms of data conversion is necessary when using both outputs together.

River survey was conducted with the following way, which locations are shown in Figure 4.1.1.

1) River profile survey : 14 km
2) River cross section survey : 38 lines（Average length of lines; 400 m
3) Bench marks for cross section : 500 m interval, 76 points on both banks

(2) Installation work of Bench Marks

At the beginning of the river survey works, the location of bench marks including 500m post and bridges for 38 cross sections were determined. In accordance with the regulation of accuracy and instruments, 76 bench marks on both banks of the river were installed with reference point of NAMRIA named TGBM-2007 as shown in Figure 3.2.11.

1) Instruments：GPS or Total station
2) Accuracy of GPS and traverse survey：1/8,000
3) Accuracy of leveling：$\pm$30 mm$\sqrt{\text{Survey distance}}$

(3) Center line Survey and Profile Survey

The survey was conducted with the following instruments:

1) HD370 digital echo sounder
2) V30 GNSS RTK GPS receivers

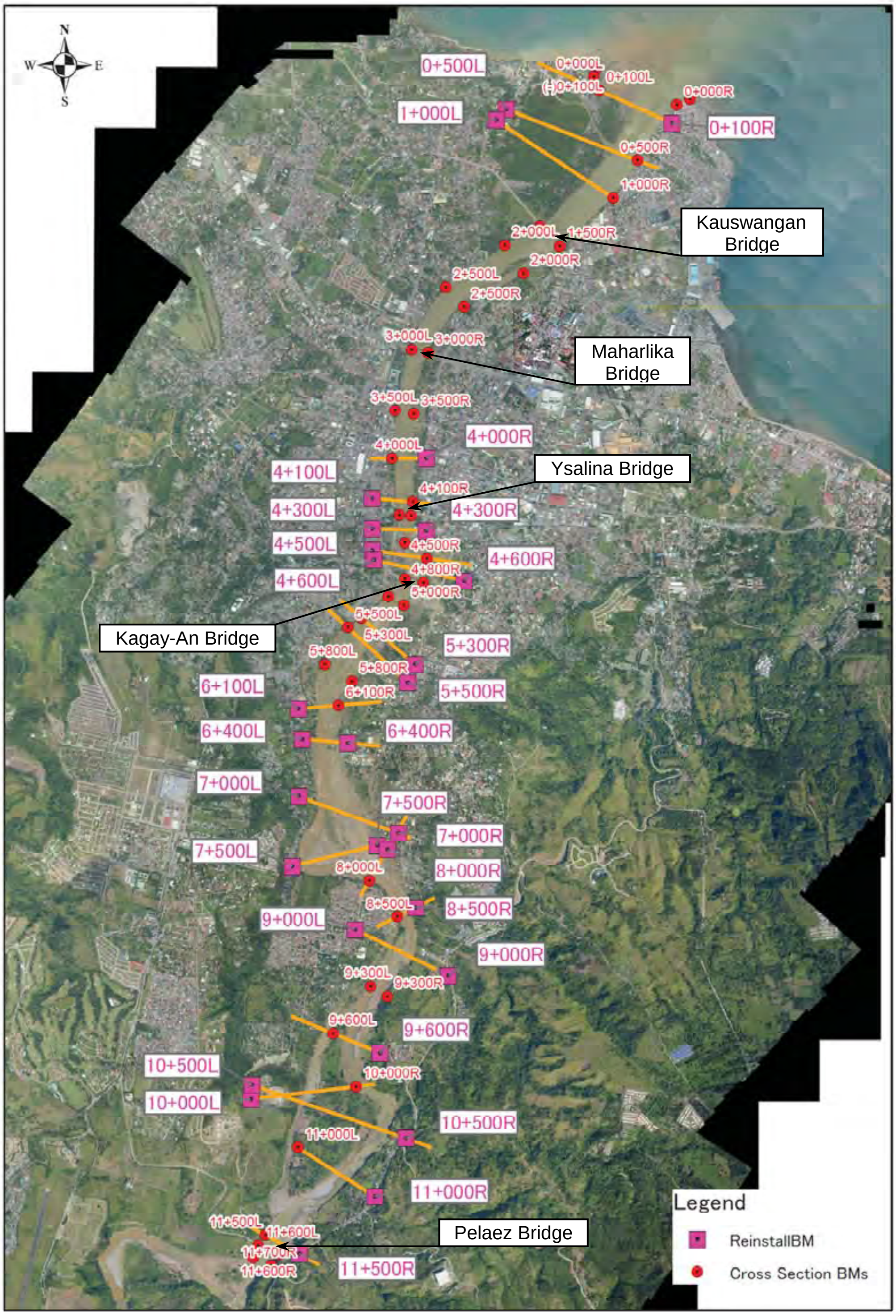
(Products of Hi-Target Surveying Instruments Co., Ltd.)

GPS Base stations were set at neighbor reference points of NAMRIA or bench marks.

(4) River cross section survey

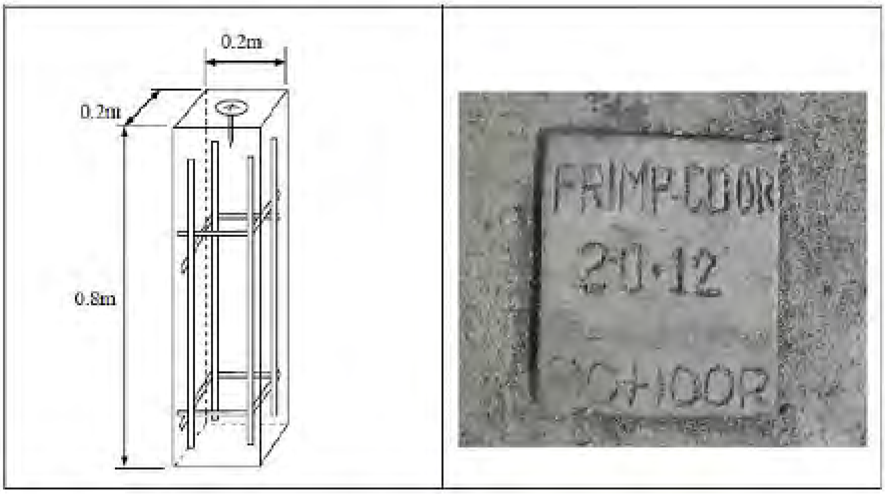
Traverse survey was conducted based on every 500m post and bench marks with the instruments and accuracy below:

1) Scope of works: 50m outside of a bench mark respectively of both banks
2) Survey points on cross section: Normally 10m to 20m interval in the river course, 3m to 5m on land, variation points of terrain and river bed, structure location and water level.
3) Instruments: GPS, Total station, Level, Echo sounder
4) Accuracy of traverse survey: At bench mark $\pm$40 mm$\sqrt{\text{survey distance}}$
5) Accuracy of survey points on profile: at bench mark ; $\pm$ 3 cm; at river bed ; $\pm$ 5 cm



Source : JICA Survey Team

Figure 4.1.1 Location of River Cross Section（Dec. 2012）



Source : JICA Survey Team

Figure 4.1.2 Sample of Bench Mark

(5) Inspection

After some adjustment for deliverables, it was finally found that the original survey(Oct. to Dec. 2012) was found to make a wrong selection for reference point. As mentioned in (2) of this section, TGBM-2007 was used for reference, however, TGBM-2011 should have been used for in the river survey as mentioned in Section 2.2.(3). Consequently all the bench marks had to be re-surveyed of its elevation.

4.2 Additional Work and Adjustment

(1) Revision of the Elelevation and Inspection Survey for Cross Section

As mentioned in (5) above, re-survey of elevation of respective bench marks was conducted from mid to end of May 2013. Inspection survey was conducted as well from beginning to mid. of June 2013. All inspection works finished on June 24th.

(2) Re-installation of Bench Mark and Presentation to DPWH

The 29 bench marks were found to have been lost at the time of June 2013 during the said inspection survey. Re-installation work was carried out in July 2013 and ended on July 29th. All the bench marks were handed over to DPWH.

4.3 Final Output of River Survey

(1) River cross section survey

The location map of river cross section is attached in Figure 3.2.12.

- Digital data of river cross section including location map
- River cross section maps
  - Scale of cross section：horizontal＝1/500、vertical＝1/500

(2) River profile survey

The river profile map is attached in Appendix A.

- Digital data of profile
- River profile maps
  - Scale of profile：Horizontal＝1/10,000、Vertical＝1/500

(3) Bench mark(see Appendix A)

- Digital data for 500 posts and its number
- List of 500m posts and its number

CHAPTER 5 ADDITIONAL RIVER SURVEY AND TOPOGRAPHIC SURVEY IN THE FEASIBILITY STUDY STAGE

5.1 Introduction

Additional river survey and topographic survey works were conducted in July and August 2013 to provide data and information required for the Feasibility design. Additional survey was composed of the followings works:

1) Establishment of horizontal and vertical controls
2) River profile/Cross-section survey, and
3) Topographic survey and mapping

5.2 Scope of Works

(1) Location of Investigation Work

Locations of the topographic survey, structural profile and river cross section surveys were determined based on the locations of the proposed river structures for the Feasibility design. Location for the river survey works is shown in Figure 5.2.1.

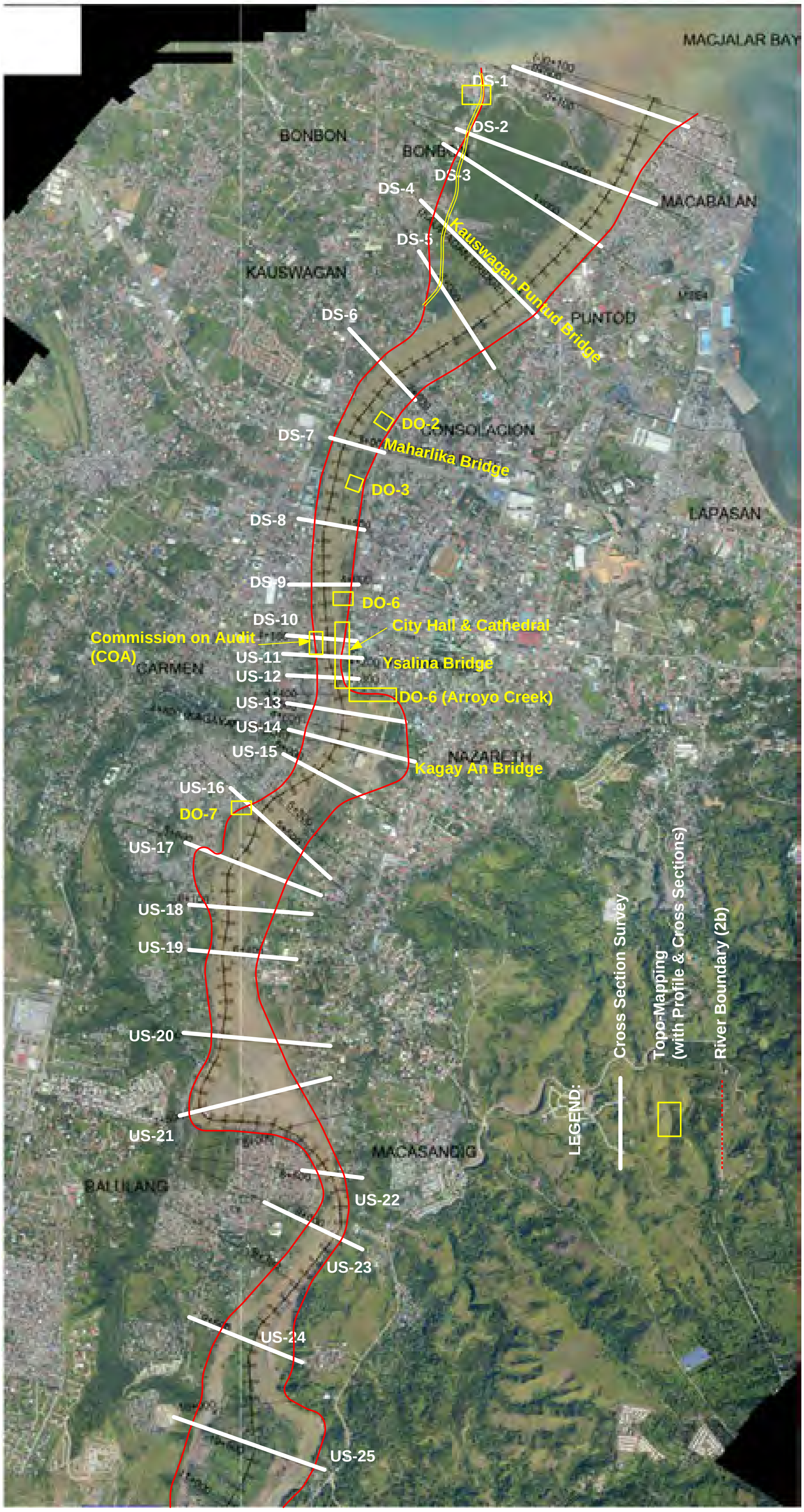
(2) Work Quantity

The additional survey works were conducted as shown in Table 5.2.1.

Table 5.2.1 Summary of Survey Works

	Work Item	Work Quantities	Note
1.	Reference Control Points		
1.1	GPS positioning	4 nos.	
1.2	Leveling with Benchmark Installation	13.5 km	
2.	Profile and Cross-section Survey		
2.1	Drainage Outlets/Creeks (5 sites)		
	Profile of Drainage Outlet/Creek	5 profiles	Total L. = 335 m
	Cross-section of Drainage Outlet/Creek	10 sections	Total L. = 20 m
2.2	Cross-Sections of Road Dike	5 Sections	Total L. = 30 m
2.3	Proposed Culverts for Road Raising (1 Location)	3 Sections	Total L. = 50 m
2.4	River Cross-section Survey, (land based)	24 Sections	Total L. = 13,500 m
2.5	River Cross-section Survey (hydrographic)	24 Sections	Total L. = 5,100 m
3.	Topographic Mapping		4.02 ha in total
	- Proposed Drainage Outlets/Creeks	0.20 ha	(4 sites)
	- Proposed Culvert Sites	0.35 ha	(1 site)
	- Proposed Floodwall (City Hall & Cathedral)	2.40 ha	
	- Proposed Floodwall (COA)	0.64 ha	
	- Arroyo Creek	0.43 ha	
4.	Relocation Survey for Geotechnical Investigation Sites	15 points	

Source: JICA Survey Team



Source: JICA Survey Team

Figure 5.2.1 Location of Additional River Survey Work Sites

5.3 Results of Survey Works

(1) Preparatory Works

1) Horizontal Control

Primary Control (GPS Survey)

The primary control network was observed with three (3) Global Positioning System (GPS) instrument considering the following manners and accuracy.

- Using GPS receivers with an accuracy of 5 mm ± 5 ppm;
- Observations were simultaneous for the 3 receivers;
- A minimum of 5 satellite signals were received at each point;
- Minimum time of observation was one (1.0) hour.

All newly established GPS horizontal control points were reckoned from MSE-49 and MSE 3328, NAMRIA's as shown in Table 5.3.1 (see certification for the base points as shown in Data Book).

Table 5.3.1 Coordination of Base Point of NAMRIA

Coordinates	MSE-49	MSE 3328
Latitude	8° 25´ 25.68065"	8° 28´ 27.32674"
Longitude	124° 36´ 45.86527"	124° 38´ 4.43699"
Northing	931438.476 m	937016.133 m
Easting	457353.796 m	459762.545 m

Note: Precision for horizontal control 1:5,000

Source: NAMRIA

2) Vertical Control

Benchmarks (BMs)

Benchmarks (BMs) were reckoned and provided based from NAMRIA's Base Point of TGBM (2011, EL. 2.2653m) located inside Macabalan Wharf, Port of Cagayan de Oro City and the BMs established in the Master Plan study stage. The BM's are established in the following accuracy and as shown in Data Book.

Limit of closure error for leveling: 10 mm $\sqrt{L}$ (length of leveling route in km)

(2) Topographic and River Cross-Section Survey Works

1) Cross-Section Survey

All cross-section stations were established based on the BMs established in MP stage and nearest traverse station and leveling authorized by NAMRIA. River cross sections are compiled in Data Book.

2) Topographic Survey

The topographic survey was carried out making use of the established horizontal control (primary or secondary) in order to record the salient features such as:

a) Existing river banks, Existing spoil sites and fishponds, Tributaries, Water course, Houses/Buildings, Bridge, Approaches and roads , Existing drainage outlet structures, and

b) Location of boreholes and test pits for geological investigation.

Topographic survey results and data concerned are compiled in Data Book.

Supporting Report
Appendix B
Geological Condition and Geotechnical Investigation

PREPARATORY SURVEY
FOR
FLOOD RISK MANAGEMENT PROJECT
FOR
CAGAYAN DE ORO RIVER (FRIMP-CDOR)
IN
THE REPUBLIC OF THE PHILIPPINES

FINAL REPORT

VOLUME III SUPPORTING REPORT (I)

Appendix B Geotechnical Investigation

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CHAPTER 1 GEOLOGICAL INVESTIGATION FOR MASTER PLAN STAGE

1.1 Introduction

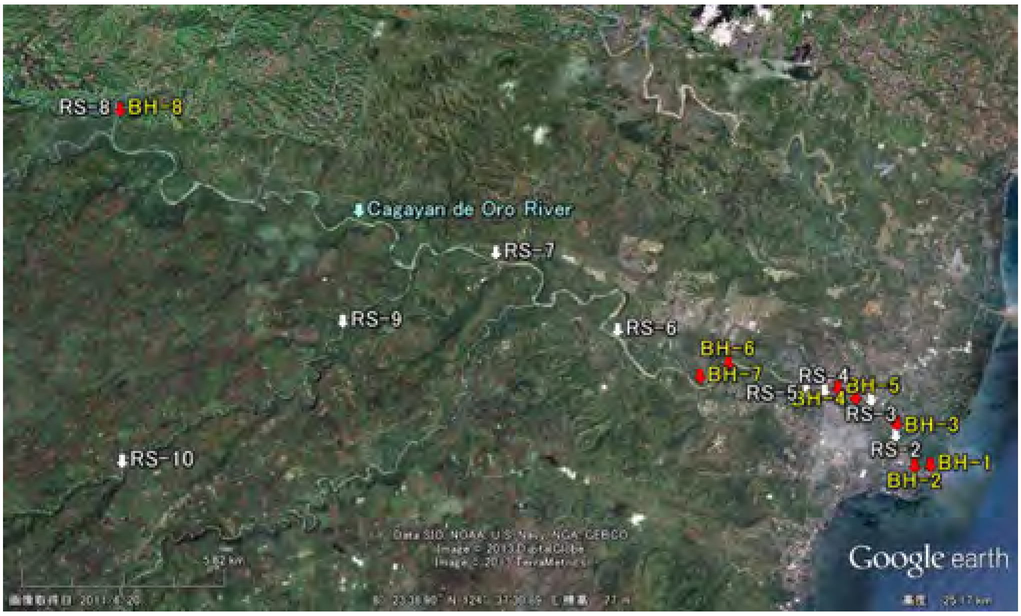
The following geological investigations were commenced from the middle of October 2012 at the Cagayan de Oro River and the Tumalaong River, which were subcontracted to a Geological Survey Firm of the Philippines.

- Boring Survey Works
- Riverbed Material Survey Works

The geotechnical investigations were conducted for the purposes of i) to examine type of structure and design dimension of river structures such as dike or revetment and ii) to know river degradation features for preparation of 1st draft design.

The locations of the survey/investigation works were determined based on structural measures proposed in the existing MP and FS of Flood Control and Drainage Projects of Selected River Basins Nationwide Package 3 (Cagayan de Oro River) and site reconnaissance for the Sabo works of the upstream reaches.

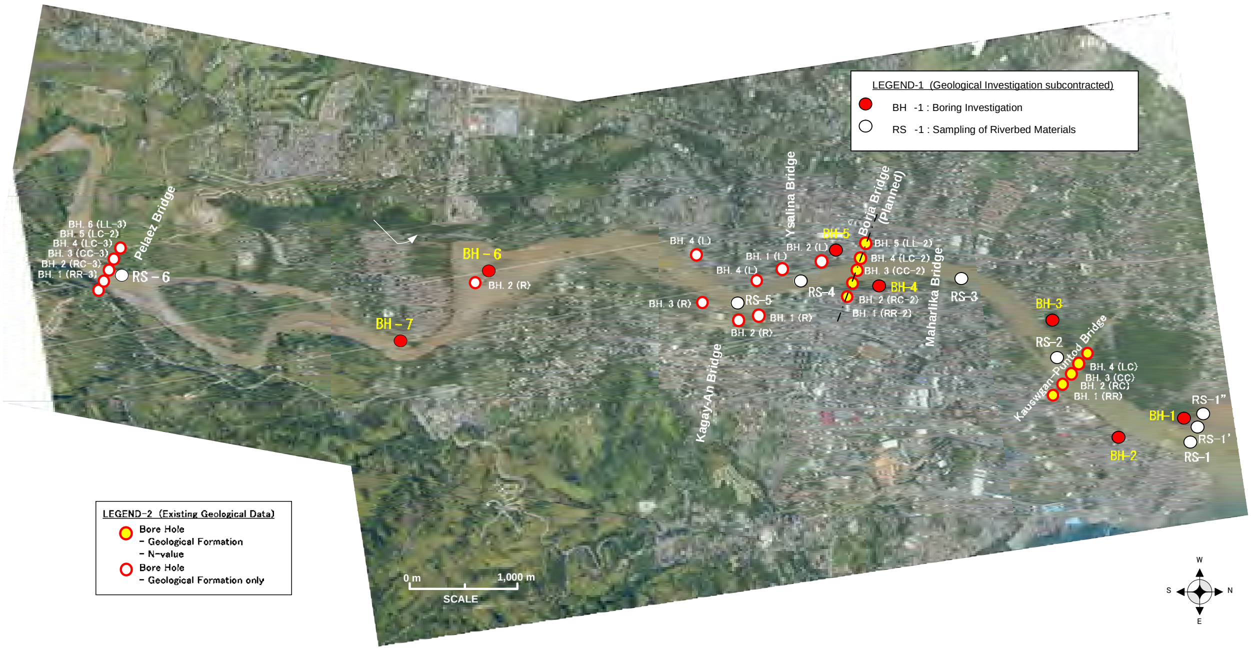
General location map of boring and riverbed material surveys is shown in Figure 1.1.1 and Figure 1.1.2



Source: JICA Survey Team

Figure 1.1.1 General Location Map of Geological Investigations

Existing geological data/information were also collected from DPWH, Regional Office-X and the Government of Cagayan de Oro City (City Engineer's Office). The existing geological surveys were carried out at the bridges or revetment construction sites along the Cagayan de Oro River as shown in Figure 1.1.2.



Source: JICA Survey Team

Figure 1.1.2 Location Map of Geological Investigation and Existing Data/Information

1.2 Geological Investigation

The geological investigations were subcontracted to a survey firm, and then carried out based on the following standards and proposed schedule as mention hereinafter.

1.2.1 Procurement of Contractor

(1) Bidding Stage

Bidding was completed as the following bidding process:

- September 18, 2012 : Preparation of bid documents and short-list of bidders
- September 25, 2012 : Sending of invitation to bid (1st)
- October 3, 2012 : Bid (1st): invalid (one bid only)
- October 5, 2012 : Sending of invitation to bid (2nd)
- October 10, 2012 : Bid (2nd): valid (four bid), bid open and Evaluation
- October 19, 2012 : Agreement of the contract

(2) Result of the Bidding

The geotechnical firm “*Advanced Geotechnical Engineering Services (AGES)*” was selected through the bidding process; bid opening, evaluation of the bid and contract negotiation.

1.2.2 Technical Standards and Criteria

(1) Boring Survey

Boring points were selected at actual flood inundation points in the past where flood flow entered into the residential area. Around locations of the boring will be required to be protected by the structural measures. The investigation covers the following four (4) major items;

1) Borehole Drilling,
2) Soil Sampling from Borehole,

3) In-Situ Test, and
4) Laboratory Tests.

Table 1.2.1 Technical Standards and Criteria for Geotechnical Investigation

Items	Technical Standard and Criteria
1) Borehole Drilling	During drilling, Standard Penetration Test (SPT), according to ASTM method D 1586, shall be conducted, and its test results shall be submitted indicating hardness/formation of the soil and coring method shall be in accordance with ASTM D 2113.
2) Soil Sampling from Borehole	The disturbed/representative soil samples shall be taken from bore holes at specified depth or interval and obtained with the use of split barrel samplers. Sampling of undisturbed samples for soft cohesive soil should be conducted in continuous and rapid motion without impact or twisting, using thin wall tube in accordance with ASTM D 1587.
3) In-Situ Test	In-situ visual identification/classification of each disturbed and undisturbed sample, including the groundwater level for each borehole shall be fully recorded, documented and reported.
4) Laboratory Tests	The presentation of the results of the tests shall conform to the applicable ASTM standards: The following tests shall be performed: i) Natural Moisture Content Test (ASTM D 4959) ii) Specific Gravity Test (ASTM D 854) iii) Particle Grain Size Distribution Test (Sieve and Hydrometer Analysis) (ASTM D 422) iv) Liquid and Plastic limits Test (ASTM D 431) v) Unit Weight Test (USBR 5370) vi) Unconfined Compression Test (ASTM D 2166) vii) One dimensional consolidation Test (ASTM D 2435) viii) Triaxial Compression Test (CU or UU) (ASTM D 2850)

Source: JICA Survey Team

The specific activities and quantity of the works to be undertaken by the contractor are summarized in Table 1.2.2.

Table 1.2.2 Summary of the Geological Investigation

Item	Quantity	Remarks
Preparation, Mobilization /Demobilization	8 holes	To start setting out survey of borehole point before placing the drilling platform.
Borehole Drilling	8 holes = 30.0m x 1hole + 10.0m x 7hole =Total 100.0 m depth	Location of each investigation site is shown in Figure 1.1.1. BH-1 (Depth=30m), BH-2(D=10m), BH-3(D=10m), BH-4(D=10m), BH-5(D=10m), BH-6(D=10m), BH-7(D=10m), BH-8(D=10m)
Sampling for Laboratory Test	8 holes	- Soil Sampling: After original ground surface with 5.0m depth intervals (100m/5.0m =20 samplings) , BH-1 (6 samples) and BH-2 to BH-8(2 samples x 7 =14samples). - Laboratory Tests: Natural moisture content, Attenberg limits, Grain-size distribution, Visual soil classification, Specific gravity, Unit weight, Plasticity of fines, Triaxial shear test, unconfined compression test, and Consolidation test, if any.
In-Situ Test	8 holes	- Standard Penetration Test (during drilling) 2.5 m depth intervals. Total 40 tests
Reporting	3 set	Geotechnical Investigation Report

Source: JICA Survey Team

(2) Riverbed Material Survey

The riverbed material survey is intended to be used as for parameter of riverbed fluctuation analysis. The investigation covers the following three (3) major items;

1) Riverbed material sampling
2) Grain size distribution analysis by sieve; and
3) Specific gravity test.

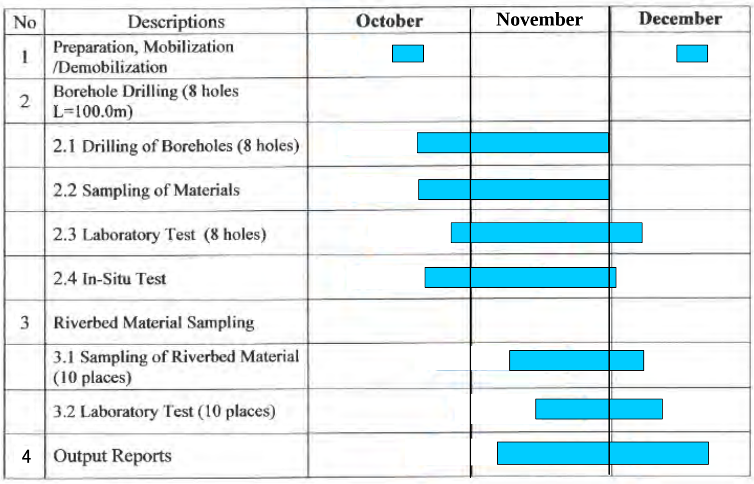
Table 1.2.3 Standards of Riverbed Material Survey

Item	Technical Standards of Survey
1) Riverbed Material Sampling	The sampling of riverbed material should be carried out at 2 points (riverbed surface and 30cm below riverbed surface) per location.
2) Grain Size Distribution Analysis by Sieve	The test sample for mechanical analysis shall be prepared in accordance with the preparation of disturbed soil samples for test under BS or ASTM. Set of standard sieves; 76.2mm, 37.5mm, 25.4mm, 10.0mm, 9.5mm, 4.75mm, 2.00mm, 0.84mm, 0.42mm, 0.25mm, 0.149mm and 0.075mm.
3) Specific Gravity Test	The specific gravity of BS1377 Test 6 "Determination of the specific gravity of soil particle" or ASTM shall be applied or any equivalent method

Source: JICA Survey Team

1.2.3 Schedule

Geological investigation works were conducted as scheduled below:



Source: The Survey Team

Figure 1.2.1 Schedule of Geological Investigation (Subcontracted)

1.3 Collection of Data

1.3.1 Approach to Data Source

Existing geological data were collected from the DPWH Region - X and City Engineer's offices of Cagayan de Oro (CDO) which previously conducted boring survey for construction of bridges and dike / revetments at the river side. The locations of existing boring survey for construction of bridges / river structures are shown in Figure 1.1.2.

1.3.2 Collected Data

(1) Geological Information

Existing geological information are available at the following construction sites which are on-going or planned as shown in Figure 1.1.2.

i) Kauswangan – Puntod Bridge Site (Left & Right Banks)
ii) Borja Bridge (Left & Right Banks) (Planned)
iii) Planned Construction of Dike, Revetment and Channel Excavation (between the Ysalina Bridge and Cala-Cala Area)

(2) N-Value (S.P.C. Test Results)

N-value results are available at the following boring survey sites for bridge construction as shown in Figure 1.3.1 (in Attachment).

i) Kauswangan – Puntod Bridge Site (Left & Right Banks)
ii) Borja Bridge (Left & Right Banks) (Planned)

The geological information was obtained from the following design drawings provided by the DPWH as shown in Table 1.3.1 (these locations are shown in Figure 1.1.2);

Table 1.3.1 Collected Existing Geological Information

No.	Title of Drawing	Geological Information of Bore-hole	River Bank Right (R) / Left (L)	Number of Bore-hole	Data Source / Date of Preparation
1	Construction of Cagayan de Oro Third Bridge (Kauwagan-Puntod Bridge) and Approaches	i) Geological Formation ii) N-value	- Right bank - Left bank - Riverbed	BH.1 (RR), BH.2 (CR), BH.3 (CC), BH.4 (CL), BH.5 (LL).	the Regional Office- X of DPWH / 1997 Sep.
2	Final Drawings Substructure Contract Drawing for Borja Bridge (Planned)	i) Geological Formation ii) N-value	- Right bank - Left bank - Riverbed	BH.1 (RR-2), BH.2 (CR-2), BH.3 (CC-2), BH.4 (CL-2), BH.5 (LL-2).	the Regional Office- X of DPWH / -
3	Plans for the Proposed Revetment and Channel Excavation (Right bank of up/downstream of the Kagay An Bridge)	i) Geological Formation	- Right bank	BH.1 (R), BH.2 (R), BH.3 (R).	the Regional Office- X of DPWH / -
4	Plans for the Proposed Revetment and Channel Excavation (Right bank of floodplain at the Kala-Kala Area)	i) Geological Formation	- Right bank	BH.4 (R)	the Regional Office- X of DPWH / -
5	Plans for the Proposed Cagayan de Oro Revetment and Flood Control (Left bank downstream of the Ysalina Bridge)	i) Geological Formation	- Left bank	BH.2 (L)	the Regional Office- X of DPWH / 1995
6	Plans for the Proposed Cagayan de Oro Revetment and Flood Control (Left bank upstream of the Ysalina Bridge)	i) Geological Formation	- Left bank	BH.1 (L) BH.4 (L)	the Regional Office- X of DPWH / 1995

No.	Title of Drawing	Geological Information of Bore-hole	River Bank Right (R) / Left (L)	Number of Bore-hole	Data Source / Date of Preparation
7	Plans for the Proposed Cagayan de Oro Revetment and Flood Control (Left bank upstream of the Kagay An Bridge)	i) Geological Formation	- Left bank	BH.3 (L)	the Regional Office- X of DPWH / 1995
8	Proposed Balulung – Macasanding PCDG Bridge South Diversion Road (Prlaez Bridge)	i) Geological Formation ii) N-value	- Right bank - Left bank - Riverbed	BH.1 (RR-3), BH.2 (CR-3), BH.3 (CC-3), BH.4 (CL-3), BH.5 (LC-3), BH.6 (LL-3),	City Engineer's Office (CDO) / 2002 Oct.

Source: Cagayan de Oro City, DPWH Region-X

1.4 Results of Investigation

1.4.1 Riverbed Material Investigation

(1) Sampling Site and Sampling Method

1) Purpose of Riverbed Material Investigation

A broad delta is formed around the estuary of Cagayan de Oro River. This delta was formed by large amounts of sediment discharge in the Late Holocene of Quaternary period, these deposits which consists of gravel and cobbles were observed at Isla de Oro area, Cala Cala area and Pelaez Bridge.

On the other hand, the fine materials which consist of sand and clay were observed around the estuary. This sediment movement is considered to be one of the characteristics of the recent sediment outflow.

The actual condition of recent sediment outflow was not figured out adequately, therefore the understanding of the outflow materials is an important survey item for the study of the outflow process.

2) Sampling Site and Sampling Method

The flood inundation occurs downstream along the river from Balulang (7-10 km upstream from the estuary, upstream of Cala Cala area). The lower terraces were distributed along the river, in which not only river structure but also houses/buildings were largely damaged by the flooding due to affect of the narrowed areas between the Ysalina Bridge and the Kagay An Bridge.

The riverbed material investigations were conducted at ten (10) sites. Five (5) sites of these were set in the flood area between the Ysalina Bridge and the estuary.

The riverbed material to be represented at each site was basically sampled at two points from three site within riverbed area; i) riverbed surface within 0.3m underneath at river flow area (site1), ii) 0.3-0.6m underneath at river flow area (site2) and iii) riverbank at edge of river flow (site2; riverside) as shown in Figure 1.4.1.

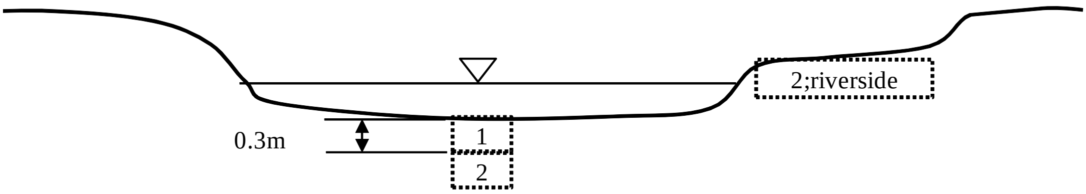
In this sampling, riverbed materials at RS-6, RS-7 and RS-8 were sampled at riverside instead of ii) site-2 due to physical site conditions (site accessibility / difficulty of sampling under water etc.).

In the estuary, two sampling sites were selected on the flood deposit materials on the left sea coast to compare with the riverbed samples.

Table 1.4.1 shows the sampling points of the riverbed materials (See Figure 1.1.1 and 1.1.2).

Table 1.4.1 Sampling Points

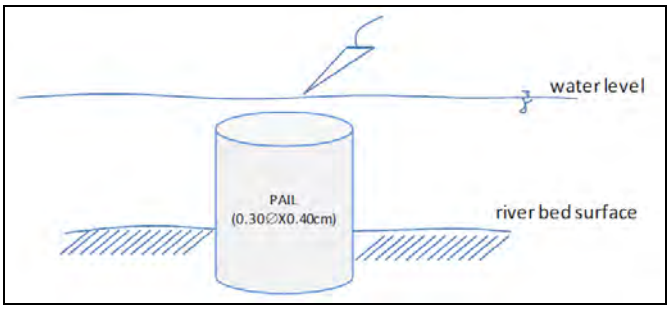
	Cagayan de Oro River								Tumalaong River	
Site	RS-1	RS-2	RS-3	RS-4	RS-5	RS-6	RS-7	RS-8	RS-9	RS-10
1	River	River	River	River	River	River	River	River	River	River
2	River	River	River	River	River	Riverside	Riverside	Riverside	River	River



Source: JICA Survey Team

Figure 1.4.1 Sampling Point

The materials should be taken with sampling tools; a scoop (small shovel) and a pall as shown in Figure 1.4.2.



Source: JICA Survey Team

Figure 1.4.2 Sampling Tool

(2) Results of Material Tests

Material tests were conducted for grain size analysis and measurement of specific gravity of the riverbed materials taken from the ten (10) sampling sites; RS-1 to RS-10.

1) Grain size analysis

Figure 1.4.3 shows the Grain size distribution curve of all samples of site1. Vertical axis is the percent passing. The precipitation test is conducted on RS-1'. Table 1.4.2 shows grain size classification.

Table 1.4.2 Grain Size Classification

(mm)

0.005	0.075	0.25	0.85	2	4.75	19	75	
Clay	Silt	Sand			Gravel			Cobble
		Fine	Middle	Coarse	Fine	Middle	Coarse	

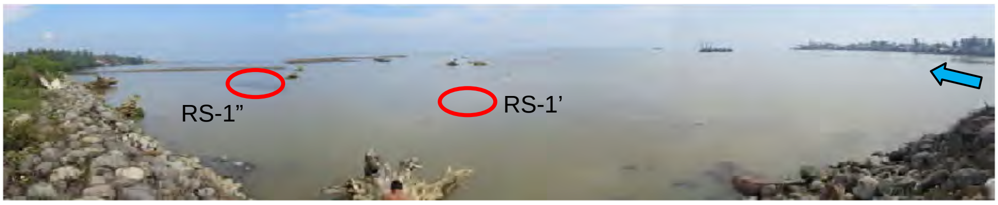
Source: the Survey Team

According to this result, the characteristic tendency is not found. But, the distribution is divided between the group (RS-1, 1', 1", 2, 3, 4, 6, 8, and 9) which consist of almost sand and the group (RS-5, 7, and 10) which consist of gravel.

Almost samples except RS-1 and RS-1' consist of sand and gravel.

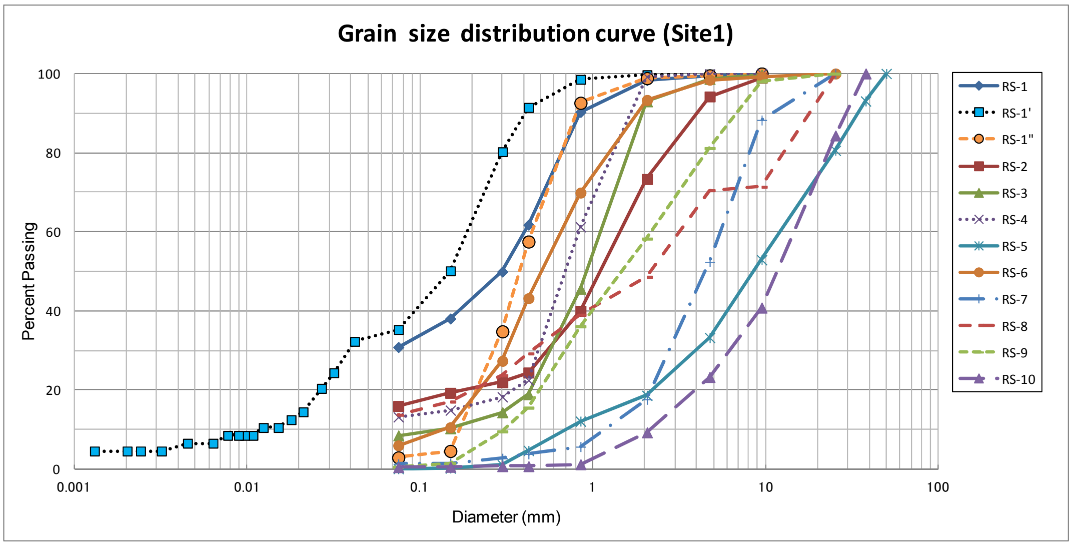
RS-1, RS-1'and RS-1" are samples taken around the estuary. RS-1" located at the farthest point from the center of riverbed consists of mainly sand without clay and silt.

It is supposed that this area is affected by river and tide.



Source: JICA Survey Team

Photo 1.4.1 Sampling Point of RS-1' and RS-1"

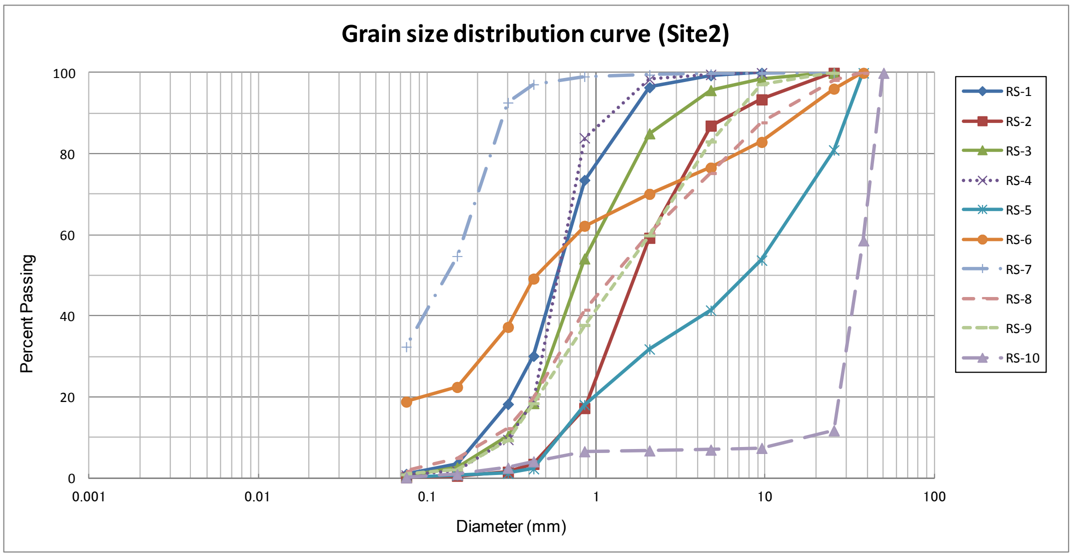


Source: JICA Survey Team

Figure 1.4.3 Grain Size Distribution Curve (Site1)

Figure 1.4.4 shows the Grain size distribution curve of all samples of site2.

According to this result, RS-6 and RS-7 have a little high percentage of silt and clay. RS-5 and RS-10 have a little high percentage of gravel.



Source: JICA Survey Team

Figure 1.4.4 Grain Size Distribution Curve (Site2)

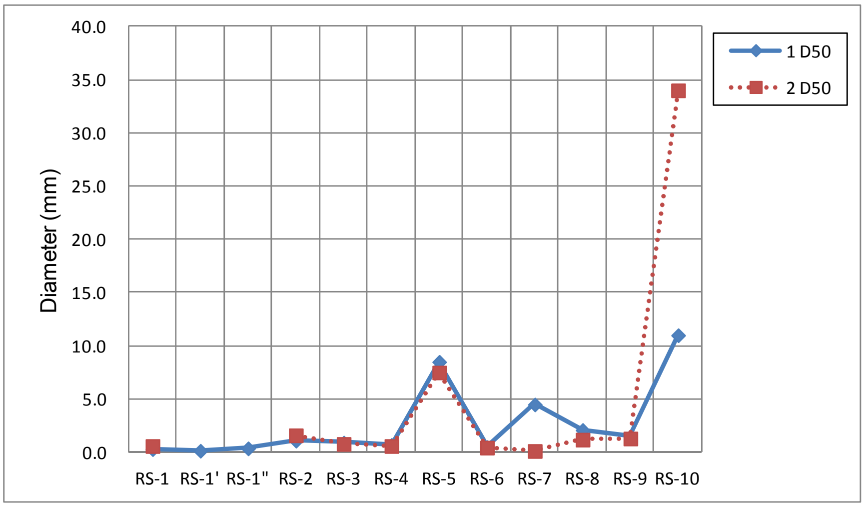
Figure 1.4.5 shows the average grain size (D50) of Site1 and Site2.

According to this result, the characteristics are as follows;

i) Site-1 and Site-2 have almost the same trend except RS-7 and RS-10.

ii) RS-5 consists of middle size of gravel of 8.0mm – 8.5mm classified into large grain size relatively. This sample was taken at the site immediately downstream of the Kagay An Bridge. This factor showing large grain size at this area was presumed that flood flow with a large traction force developed at river narrow section between the Kagay An and Ysalina Bridges causing washing out of fine materials.

iii) RS-10 is located at the Mand Steal Bridge site damaged by the Sendong. Many gravels and cobbles are observed at surface riverbed in this area. That characteristic is considered to be reflected in the result.



Source: JICA Survey Team

Figure 1.4.5 Average Grain Size (D50) of Site1 and Site2

2) Specific gravity

Table 1.4.3 shows specific gravity of grains. The maximum is 2.86, the minimum is 2.68 and the average is 2.77.

Table 1.4.3 Specific Gravity

	1	2	Ave
RS-1	2.69	2.70	2.70
RS-2	2.68	2.77	2.73
RS-3	2.79	2.72	2.76
RS-4	2.76	2.77	2.77
RS-5	2.80	2.83	2.82
RS-6	2.76	2.80	2.78
RS-7	2.73	2.77	2.75
RS-8	2.72	2.78	2.75
RS-9	2.85	2.86	2.86
RS-10	2.78	2.79	2.79
Ave	2.76	2.78	2.77
Max	2.85	2.86	
Min	2.68	2.70	

Source: JICA Survey Team

1.4.2 Geological Investigation

(1) Drilling Point and Investigation Works

Soil boring survey was conducted to obtain geological information introduced from in-situ and laboratory tests such as standard penetration test (SPT for N-value) and grain size analysis in order to design structural foundation and earth dike.

Soil boring surveys were conducted at eight (8) locations (BH- 1 to 8). These seven (7) drilling points were set in flood inundation areas where are downstream of Cala Cala and Macasanding. Drilling hole of BH-8 was conducted about 30 km upstream site from the estuary of the Cagayan de Oro River to examine the foundation of Sabo facilities. (See Figure 1.1.1 and Figure 1.1.2).

(2) Result of Drilling Investigation

N-value (results of SPT) and the geological information are shown in Table 1.4.4. Each drilling (borehole) logs are attached in DATA BOOK, Appendix O “Geotechnical Investigation Data ”.

According to Table 1.4.4, the geological informations are divided into two zones that are the zone which consists of mainly gravels and the zone which consists of sand and clay.

The zone which consists of mainly gravels is observed from 0m to 10m depth, the zone which consists of sand and clay is seen in deeper zone than 5m depth of BH-1.

Drilling works at BH-6 and BH-7 were discontinued at 5m depth because the boulders which are too hard to drill were distributed at the depth. Riverbed deposit layer was confirmed also at BH-8.

Table 1.4.4 Result of Geology Investigation (Geology and Standard Penetration Test)

	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6	BH-7	BH-8
Depth (m)	30	10	10	10	10	10	2.61	10
5.0	Fine-medium sand with fine gravel Gray N : 10 (4.55-5.0)	Silty Sand Gray N : 4 (5.0-5.45)	Sand and Gravel Gray N : 5 (4.55-5.0)	Silty Sand Dark gray N : 4 (5.0-5.45)	Fine-medium Sand with silt Gray N : 7 (5.0-5.45)	Clayey Silt Gray N : 8 (4.55-5.0)	Gravel Gray N > 50 (2.5-2.61)	Boulder (basaltic andesite) Gray
10.0	Sandy Silt Dark brown N : 8 (10.0-10.45)	Clayey Silt with sand Gray N : 4 (9.55-10.0)	Gravel with sand Gray N : 7 (9.55-10.0)	Sandy Gravel Dark gray N : 13 (9.55-10.0)	Gravel with sand Gray N : 20 (9.55-10.0)			Boulder (basaltic andesite) Gray
12.5	Silty Sand Dark gray N : 9 (12.0-12.45)							
15.0	Sand and Silt Gray N : 9 (14.55-15.0)							
17.5	Sandy Silt Gray N : 11 (17.05-17.5)							
20.0	Silt with Sand Glayish brown N : 12 (20.0-20.45)							
22.5	Clayey Silt Gray N : 6 (22.05-22.5)							
25.0	Clayey Silt Gray N : 11 (25.0-25.45)							
27.5	Clayey Silt Gray N : 9 (27.05-27.5)							
30.0	Clayey Silt Gray N : 11 (29.55-30.0)							

Legend

Clayey Silt	Sandy Silt Silt with Sand	Silty Sand Sand with silt Sand and Silt	with fine gravel Sand and Gravel	Gravel Sandy Gravel Gravel with sand	Boulder

(mm)

0.005	0.075		0.25	0.85	2	4.75	19	75
Clay	Silt	Sand			Gravel			Cobble
		Fine	Middle	Coarse	Fine	Middle	Coarse	

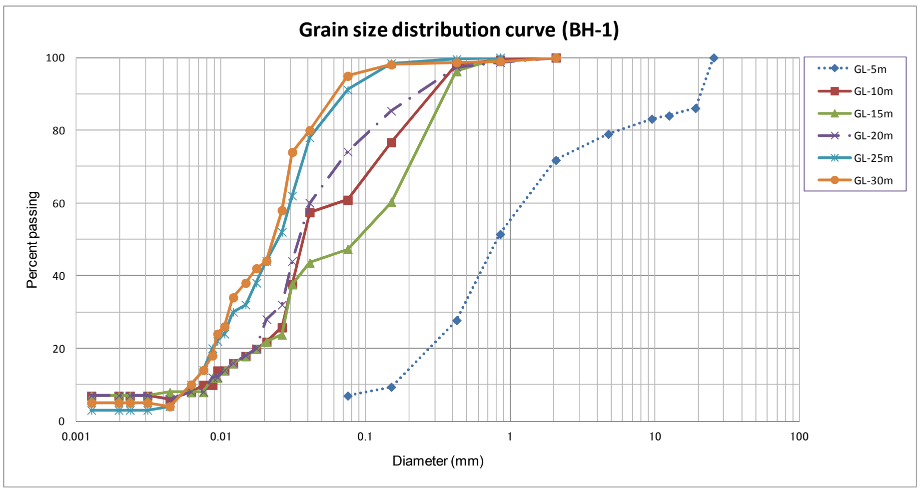
Source: JICA Survey Team

(3) Result of Material Tests

The grain size analysis, the measurement of specific gravity and the compressive strength test were conducted on the soil samples from the boreholes.

1) Grain size analysis

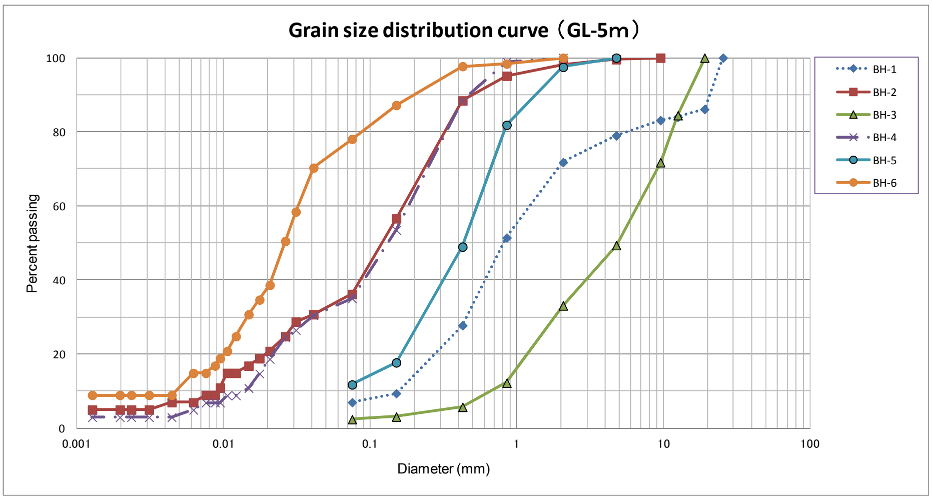
Grain size distribution curve of BH-1 (0-30m) is shown in Figure 1.4.6. Difference of grain size at this hole is clearly shown in which there are two type of materials divided at 5 m depth underneath. The grain size of materials of riverbed surface layer within 5 m depth underneath is 10 times bigger than the materials at layer 5-30 m depth.



Source: JICA Survey Team

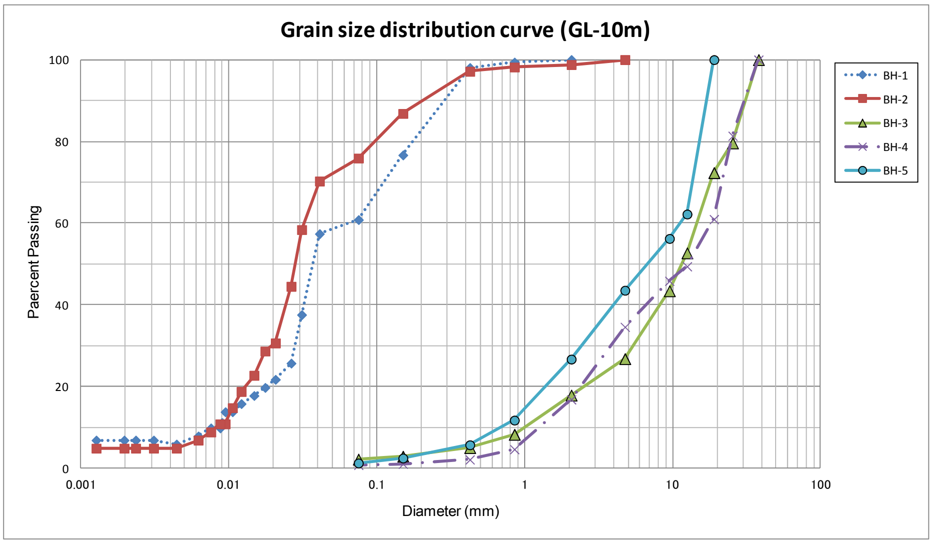
Figure 1.4.6 Grain Size Distribution Curve (BH-1)

The grain size distribution curves of 5 m depth and 10 m depth are shown in Figure 1.4.7 and Figure 1.4.8. As shown the results, the grain size distribution curves are divided into the group which has a high percentage of sand/clay and the group which has a low percentage of that, respectively. Especially, the group of 10m depth has that trend obviously.



Source: JICA Survey Team

Figure 1.4.7 Grain Size Distribution Curve (Depth : 5m)



Source: JICA Survey Team

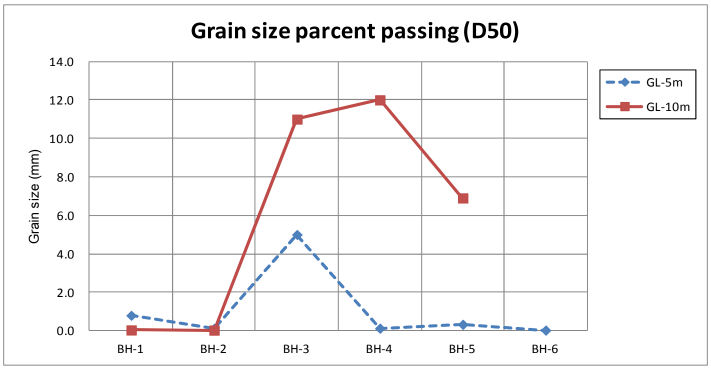
Figure 1.4.8 Grain Size Distribution Curve (Depth : 10m)

Average grain size (D50) of materials which were taken from 5 m to 10 m depth underneath is shown in Figure 1.4.9.

As shown Figure 1.4.9, grain sizes are divided into sand group and gravel group (Table 1.4.5). This difference is considered to be shown the difference of the tractive force at the sampling point.

(mm)

	GL-5m	GL-10m
BH-1	0.80	0.04
BH-2	0.12	0.03
BH-3	5.00	11.00
BH-4	0.13	12.00
BH-5	0.33	6.90
BH-6	0.03	—



Source: JICA Survey Team

Figure 1.4.9 Average Grain Size (D50)

Table 1.4.5 Group of Sand and Gravel

< 2mm		2mm <	
5m	10m	5m	10m
BH-1 BH-2 BH-4 BH-5 BH-6	BH-1 BH-2	BH-3	BH-3 BH-4 BH-5

Source: JICA Survey Team

2) Specific gravity

Table 1.4.6 shows specific gravity of each sample at depth and location. The specific gravity is measured to be 2.78 in maximum and 2.64 in minimum, and its average value is estimated to be 2.72.

Table 1.4.6 Specific Gravity

Depth	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6	Ave
5m	2.70	2.72	2.76	2.73	2.78	2.67	2.73
10m	2.72	2.71	2.71	—	2.77		2.73
15m	2.70						2.70
20m	2.67						2.67
25m	2.64						2.64
30m	2.66						2.66
Ave	2.68	2.72	2.74	2.73	2.78	2.67	2.72
Max	2.72	2.72	2.76	2.73	2.78	2.67	2.78
Min	2.64	2.71	2.71	2.73	2.77	2.67	2.64

Source: JICA Survey Team

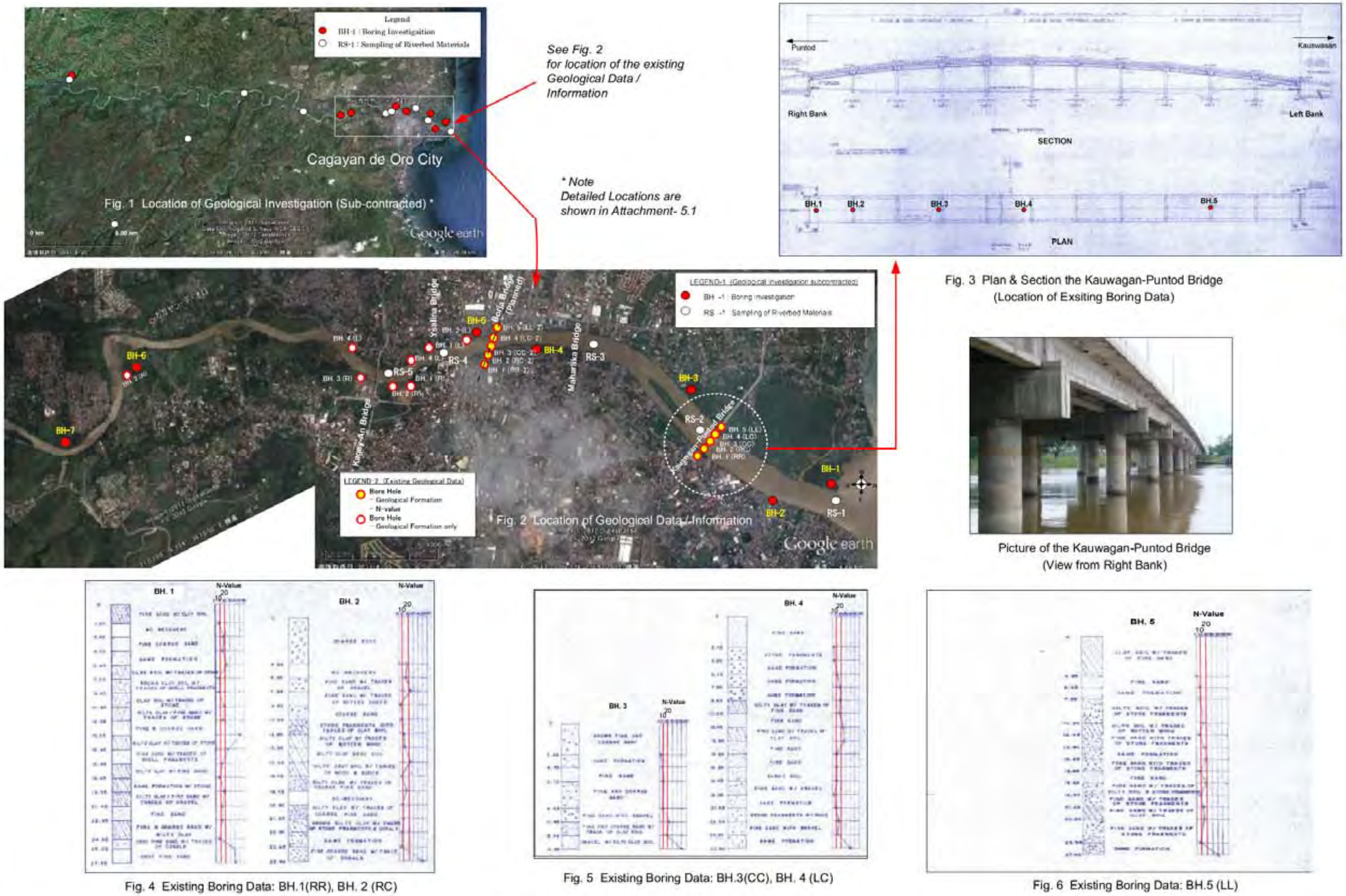
3) Compressive strength

Boulders of andesite were confirmed at BH-8 site. Compressive strength of sampled materials taken from BH-8 was measured under laboratory testing. The results of the test are shown in Table 1.4.7.

Table 1.4.7 Compressive Strength of BH-8

	Depth	kPa (kN/m^2)	Geology
BH-8	4.50-4.70m	19064.51	Andesite
	9.00-9.15m	47989.97	

Source: JICA Survey Team



Geological Formations and N-values at the Kauwagan-Puntod Bridge

Figure 1.3.1 Geological Data and Information (1/4)

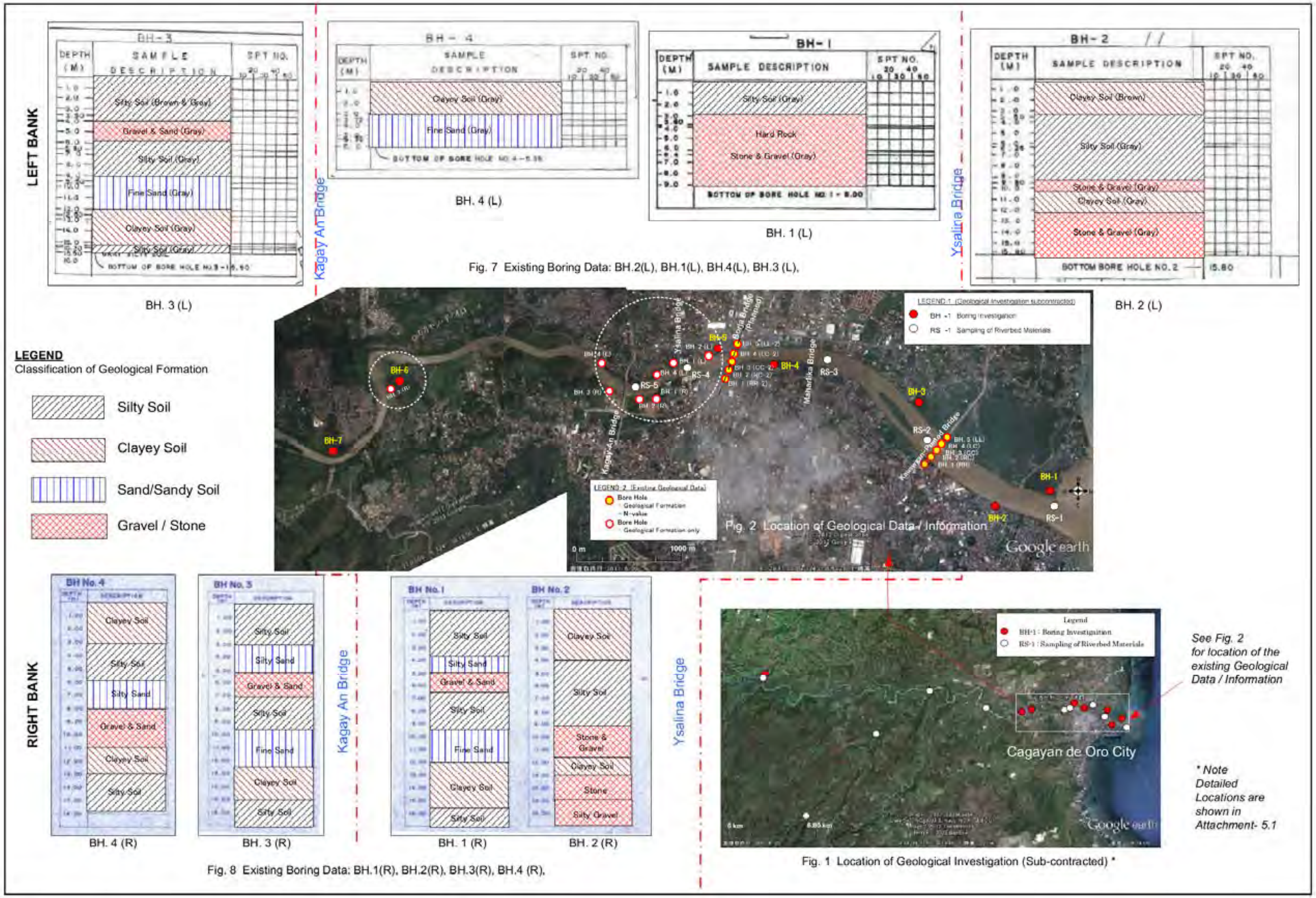


Figure 1.3.1 Geological Data and Information (2/4)

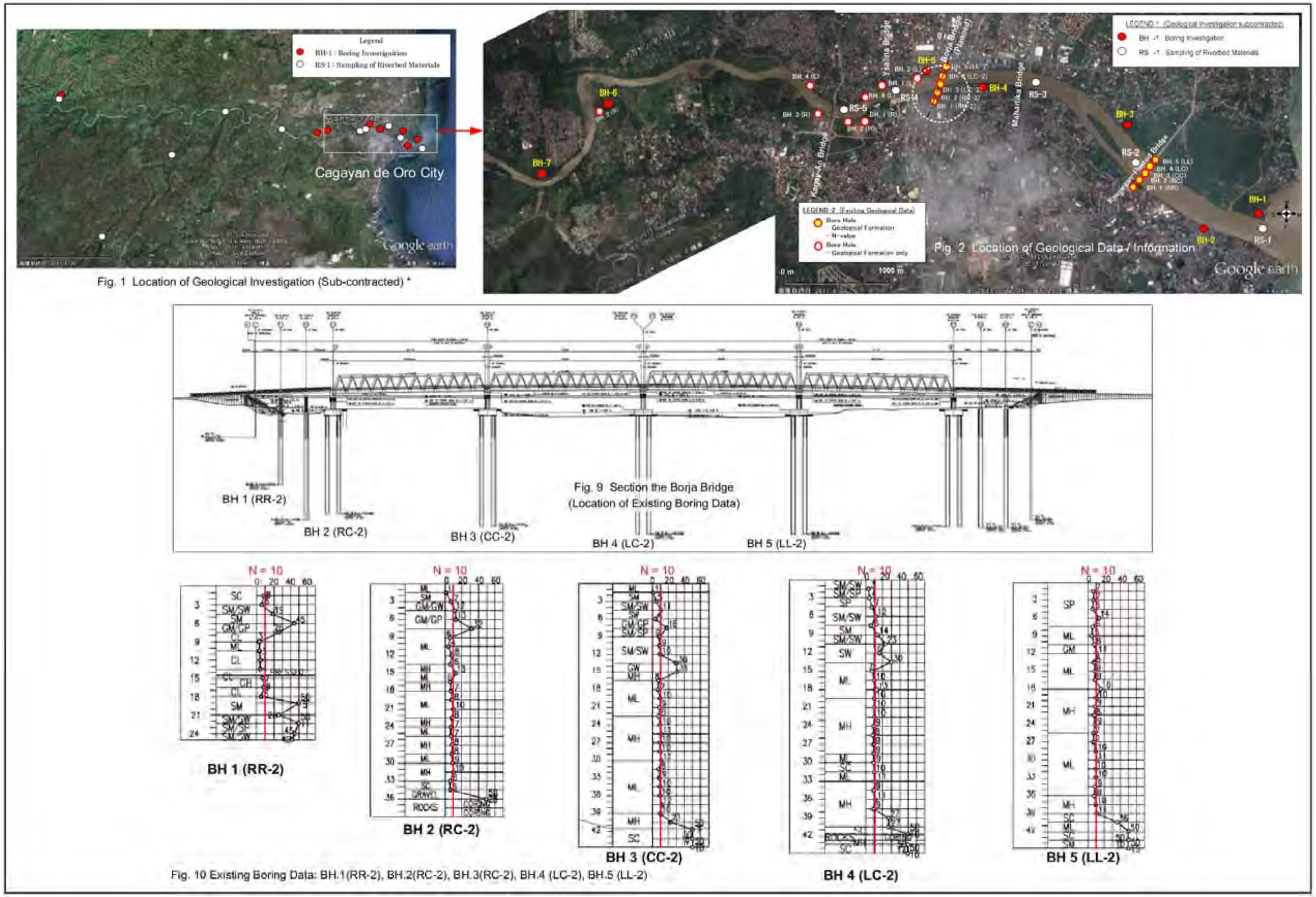
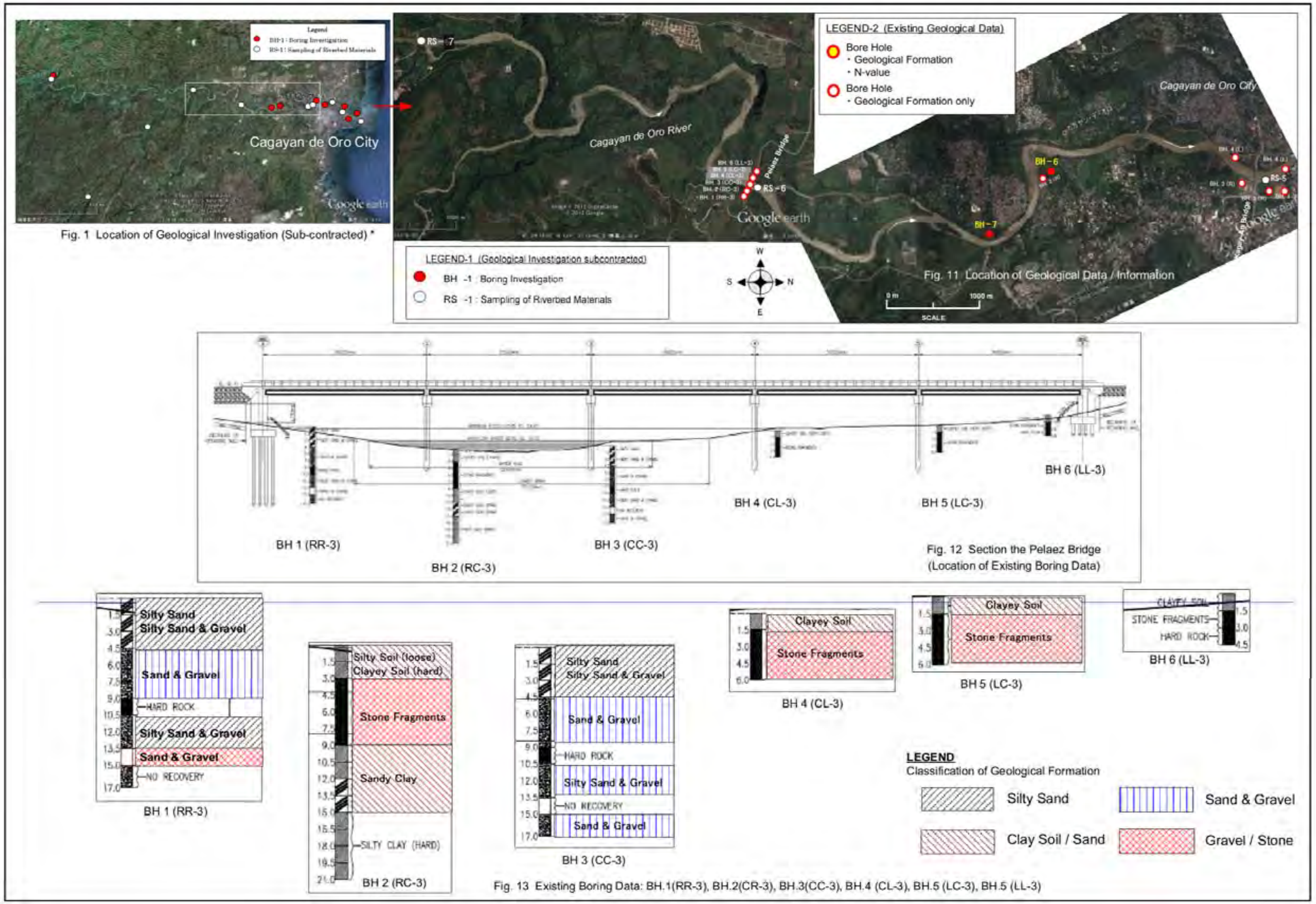


Figure 1.3.1 Geological Data and Information (3/4)



Source: JICA Survey Team

Figure 1.3.1 Geological Data and Information (4/4)

CHAPTER 2 ADDITIONAL GEOTECHNICAL INVESTIGATION FOR FEASIBILITY STUDY

2.1 Introduction

Additional geotechnical investigation at site works were conducted from June 18, 2013 to August 16, 2013, which were prepared based on locations and type of structural measures, the previous geotechnical investigation results during Master Plan stage and collected existing geological data.

The additional geological investigations were subcontracted to a survey firm, and then carried out based on the following standards and proposed schedule as mention hereinafter.

2.2 Geological Investigation

2.2.1 Procurement

(1) Bidding Stage

The Bidding process proceeded as follows:

- March 25, 2013 : Preparation of bid documents and short-listing of bidders
- May 17, 2013 : Pre-Bid Meeting, Conference
- May 22, 2013 : Pre-Bid Meeting, Site Inspection along the Cagayan de Oro River
- June 11, 2013 : Bid Opening
- June 13, 2013 : Pre-Award Meeting
- June 18, 2013 : Signing of Contract Agreement
  Issuance of Notice to Proceed

(2) Result of the Bidding

The Contract was awarded to "*George B. Padilla & Associates*" which was selected through the bidding process as the lowest bidder and regarded as the most compliant.

2.2.2 Technical Specifications

(1) Scope of Work

The investigation covers five major items; (i) Borehole Drilling, (ii) Test Pits, (iii) Soil Sampling from Boreholes/Test Pits, (iii) In-Situ Test, and (iv) Laboratory Tests.

1) Location of Investigation Work

The borehole and test pit locations for the additional geotechnical investigation works were selected from the proposed structural measures in the Master Plan of this study (FRIMP-CDOR). Location Map for the Additional Geotechnical Investigation Works is shown in Figure 2.2.1 including locations of geotechnical investigations of the Master Plan Study.

a) Boreholes (FB): 11 sites
  - FB-1 : for proposed culvert
  - FB-2 : for proposed evacuation road/ dike
  - FB-4, 6, 12 and FB-14 : for proposed dikes
  - FB-5, 7, 8, 10, 11 and FB-13 : for proposed drainage sluice gates

b) Test Pits (FP): 4 sites

FP-1 to FP-4 : for possible borrow source of materials

Source: JICA Survey Team

Figure 2.2.1 Location Map of Additional Investigation Work

2) Quantity and Parameters of Works

The specific activities and quantity of the works to be undertaken by the Contractor are summarized in Table 2.2.1. The Summary of Quantities is also presented herein as Table 2.2.2.

Table 2.2.1 Summary of Quantities

Item	Quantity	Remarks
Mobilization /Demobilization	11 Locations	Location of each borehole shall be confirmed by JICA Study Team
Borehole Drilling (Rotary) and Standard Penetration Test (SPT)	11 Holes Total Depth = 250 m.	Locations of each investigation site are as shown in Figure 2.2.1 FB-1,2,4,6,7,8,10,11,12,13 & 14 = 250 m.
Test Pits	4 Locations	For investigation of possible borrow source materials
Material Sampling for Laboratory Test : **Disturbed Soil Sampling** - Boreholes - Test Pits - Laboratory Tests **Undisturbed Soil Sampling** - Boreholes - Laboratory Test	 100 Samples 4 Samples 104 Nos. 25 Samples 11 Nos. 25 Nos.	 Disturbed Soil Sampling = 104 Samples - taken at every 2.50 m. depth interval - taken at bottom portion of pit - for Nat. Moisture Content, Atterberg Limits, Grain Size Distribution, Specific Gravity, etc. Undisturbed Soil Sampling = 25 Samples - taken at every 10.00 m. depth interval - for Tri-axial Shear Test and - Consolidation Test
In-Situ Test	250 Nos.	- Visual Soil Classification - SPT at every 1.0 m. interal
Reporting	3 Sets	Geotechnical Investigation Report

Source: JICA Survey Team

Table 2.2.2 BOQ of Additional Geological Investigations

ITEM	No. of Survey		Quantity-Unit		Total Quantity		Unit Price	Amount
	No.	Unit	Qty.	Unit				
Mobilization / Demobilization					1	lot		-
Leveling	16	site	1	set	0	set		-
Position Survey	16	site	1	set	0	set		-
Equipment Setting	11	site	1	set	11	set		-
Borehole Drilling	11	site			250	m		-
- FB 1	1	site	40	m	40	m		-
- FB 2	1	site	30	m	30	m		-
- FB 3	0	site	0	m	0	m		-
- FB 4	1	site	30	m	30	m		-
- FB 5	0	site	10	m	0	m		-
- FB 6	1	site	10	m	10	m		-
- FB 7	1	site	30	m	30	m		-
- FB 8	1	site	10	m	10	m		-
- FB 9	0	site	0	m	0	m		-
- FB 10	1	site	20	m	20	m		-
- FB 11	1	site	30	m	30	m		-
- FB 12	1	site	10	m	10	m		-
- FB 13	1	site	20	m	20	m		-
- FB 14	1	site	20	m	20	m		-
Sub -Total for Drilling					**250**	**m**		**-**
								-
Test Pit Survey (FP-1 to FP-4)	4		4	4	4	units		-
Standard Penetration Test	11		1	interval	250	sets		-
Soil Sampling								-
- Disturbed Soil Sampling (Borehole)	11		2.5	m	100	sets		-
- Disturbed Soil Sampling (Test Pit)	4		at pit bottom		4	units		-
- Undisturbed Soil Sampling (Borehole)	11		10	m	25	sets		-
- Undisturbed Soil Sampling (Test Pit)	5		at pit bottom		0	units		-
Laboratory Test (Disturbed)								
- Specific Gravity	15				104	samples		-
- Moisture Content	15				104	samples		-
- Gradation (Sieve Analysis)	15				104	samples		-
- Liquid Limit / Plastic Limit	15				104	samples		-
- Wet Unit Weight of Soil	15				104	samples		-
Laboratory Test (Undisturbed)								
- Uni-axial Shear Test	15				0	samples		
- Tri-axial Shear Test	15				11	samples		-
- Consolidation Test	16				25	samples		-
Reporting (Geotechnical)					1	lot		-
Sub -Total for Test Pit, Laboratory Tests and Reporting								**-**
Total								-
VAT (12%)								-
GRAND TOTAL								-

Contract Price -

Source: JICA Survey Team

(2) Technical Standards, Criteria and Methodology

1) Borehole Drilling

For the purpose of determining the sub-surface condition and foundation soil properties at each site, the work shall be carried out involving rotary drilling to collect soil samples and perform in-situ standard penetration tests. Wash Boring method of drilling shall not be adopted.

Location of borehole shall be confirmed by Consultant prior to commencement of setting-up and drilling operations. During drilling, Standard Penetration Test (S.P.T.), according to ASTM Method D 1586, shall be conducted, and its test results shall be submitted indicating hardness/formation of the soil, and core drilling procedure etc. After backfilling of borehole, the location shall be clearly marked with concrete cover indicating the Borehole Identification and date of activity including a flag with wooden pole for subsequent confirmation of GPS location and natural ground elevation.

When rock formation, hard strata or gravel layer is encountered, coring method shall be applied to complete the required depth. All cores shall be stored in sturdy and properly labeled core boxes. Depth of coring runs shall be clearly delineated and properly marked with indelible ink. Core drilling procedure should be in accordance with ASTM D 2113.

Cores recoveries shall be monitored as percentage of the Coring Run.

$$\text{Core Recovery} = \frac{\text{Total Core Recovery}}{\text{Total Coring Run}} \times 100\%$$

The RQD Values (Rock Quality Designation) shall likewise be obtained as follows:

$$\text{RQD} = \frac{\text{Sum of Cores 100 mm}}{\text{Total Core Recovery}} \times 100\%$$

Borehole drilling shall be, basically, complete up to each specified boring depth. However, borehole drilling may be judged completed/terminated when a geological layer of N-value greater than 20 (N>20) is encountered and which are subject to decision by JICA Study Team representative on site.

2) Test Pits

Test Pits are generally intended to obtain the consistency of the soil material at designated locations for the purpose of acquiring possible borrow source materials.

The test pit shall be manually or mechanically dug at designated locations and approved by the consultant representative at site. The pit shall have an area of at least 1.5 m. x 1.5 m. and a depth of 2.0 m. The topmost 0.5 m. layer shall be disregarded and disturbed representative samples shall be taken for laboratory testing.

3) In-situ Tests and SPT

The topmost 0.5 meter from each borehole/test pit shall be disregarded. In-situ visual identification/classification of each disturbed and undisturbed sample and SPT, including the groundwater level for each borehole shall be fully recorded, documented and reported. For the purpose of the aforementioned, all samples shall be placed in a wooden core box, properly labeled and photographed for proper identification and documentation.

The Standard Penetration Tests shall be conducted every 1.0 m. interval throughout the depth of each designated borehole and at every change in strata. The starting depth of performing SPT shall be 1.0 m. or 2.0 m. below the natural ground level.

4) Soil Sampling from Boreholes/Test Pits

The disturbed/representative soil samples shall be taken from bore holes at every 5.0 m intervals and obtained with the use of split spoon samplers.

Undisturbed samples shall be obtained using a thin walled (Shelby) tube sampler. Sampling for soft cohesive soil should be in continuous and rapid motion without impact or twisting, using thin wall tube and in accordance with ASTM D 1587.

All recovered samples scheduled for laboratory testing shall be placed in double plastic bags. The plastic bag containing the samples shall be properly labeled with the following information: site, borehole number, SPT blow count, depth where sample was taken and date of sampling.

5) Laboratory Tests

Laboratory tests shall be carried out to determine the required properties of the soil.

Samples for testing shall be selected and scheduled by the Contractor and confirmed by the JICA Study Team.

All soil samples scheduled for testing shall be tested within 24 hours after samples have been delivered to the laboratory.

Where applicable, test shall be performed in accordance with the procedure listed in this Specification and applicable ASTM Standards. The presentation of the results of the tests shall conform to the applicable ASTM Standards:

i) The following tests shall be performed:
ii) Visual Soil Classification (USCS)
iii) Natural Moisture Content (ASTM D 4959)
iv) Specific Gravity Test (ASTM D 854)
v) Particle Grain Size Distribution (Sieve and Hydrometer Analysis) (ASTM D 422)
vi) Liquid and Plastic limits (ASTM D431)
vii) Unit Weight (USBR 5370)
viii) One dimensional consolidation (ASTM D 2435)
ix) Tri-axial Shear Test (CU or UU) (ASTM D2850)

6) Reporting

The geotechnical investigation report shall contain the subsurface investigation findings, evaluation and recommendations, borehole logs, actual borehole location plan, subsurface profiles, laboratory tests results, and other necessary information. All units of measurement should be metric. Borehole logs and subsurface profiles shall use the standard Unified Soil Classification (USCS) symbols and designations. A photograph of each site, illustrative of site condition and terrain features shall be made and included as part of the report.

The report should include the recommended foundation type for the following:

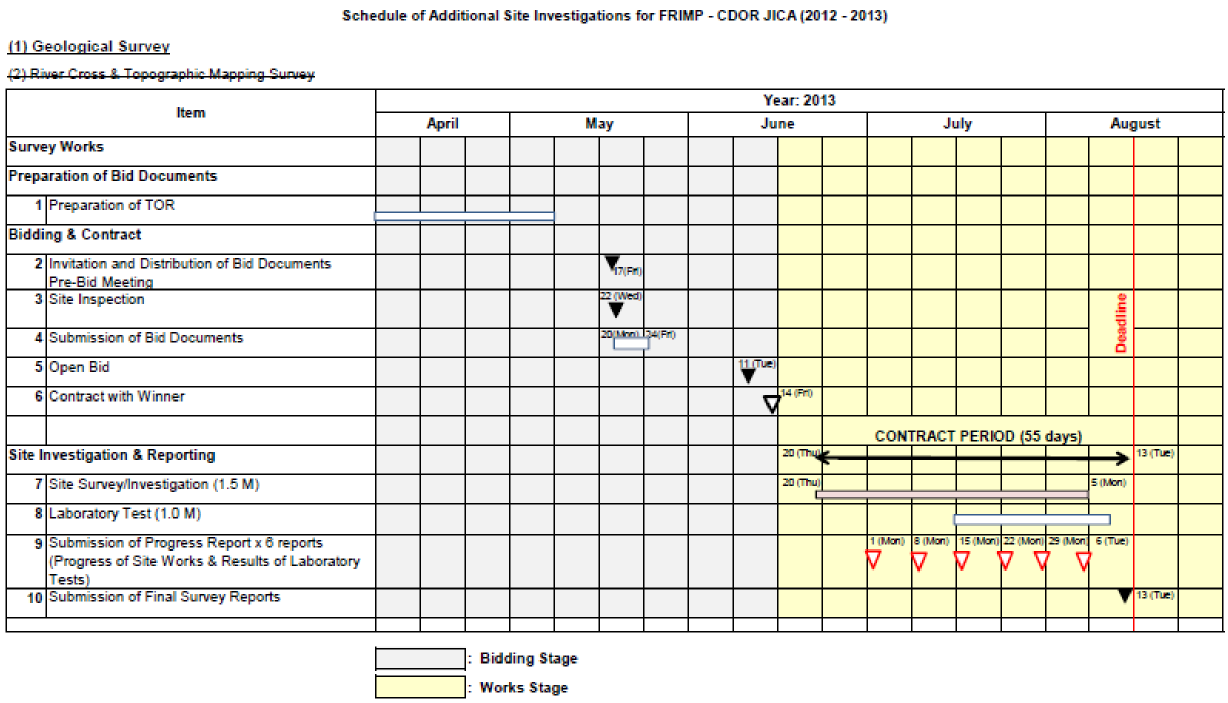
- Shallow footing, the allowable soil bearing capacity, consolidation and settlement, liquefaction and shear failure considerations.
- Important construction consideration in foundation excavation, pile driving, pile load testing, soil stabilization requirements, etc.

(3) Work Schedule

1) Schedule of the Works

The work shall be completed within sixty (60) calendar days including mobilization, fieldwork, laboratory analyses and preparation/submission of final report, from the date of commencement of activities issued by the JICA Study Team.

The schedule of work activities for the Additional Geotechnical Investigation Work is shown hereunder as Figure 2.2.2.



Source: JICA Survey Team

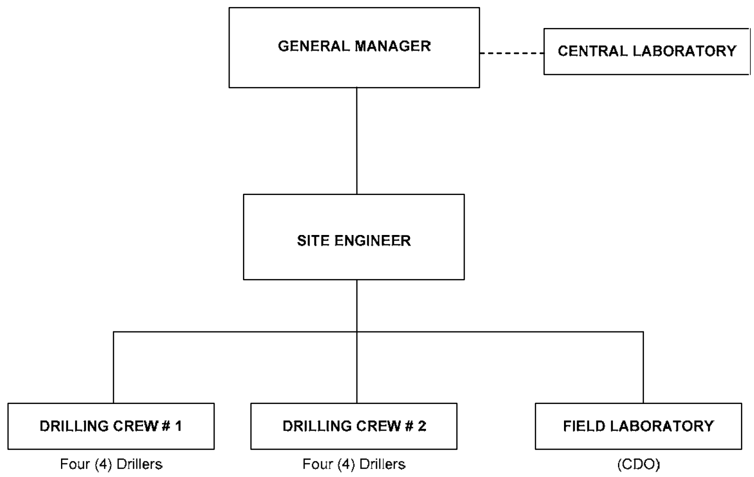
Figure 2.2.2 Schedule of Additional Geotechnical Investigation Work

2) Organization of the Works

Meetings between the Consultant and the Contractor shall be held periodically and as required to confirm work progress and to solve problems encountered.

In order to ensure completion of the works within the schedule, the Contractor shall organize working groups of the drilling works.

The Contractor shall also assign an overall site manager for the geotechnical investigation works to be conducted in the sites. The site manager shall be the contact person for the JICA Study Team as well as their Field Assistant Engineers/Supervisors/Staff as shown in Figure 2.2.3.



Source: JICA Survey Team

Figure 2.2.3 Organization Chart of Additional Geotechnical Investigation Work

2.3 Collection of Data

2.3.1 Location and Depth of Geological Investigation

The Investigation works were undertaken at 11 Boreholes and 4 Test Pits sites as shown in Table 2.3.1.

Table 2.3.1 Location and Depth of Boreholes and Test Pits

Borehole/ Test Pit	Coordinates		Depth (m)	Ground Elevation (EL,m)	Location / Barangay
	Northing	Easting			
FB-1	940747.51	461160.93	40.00	1.934	Bgy. Bonbon
FB-2	940375.81	460993.85	30.00	1.139	Bgy. Bonbon
FB-4	939239.37	461054.82	30.00	1.064	Bgy. Consolacion
FB-6	938838.37	460531.72	10.00	1.168	Bgy. Consolacion
FB-7	938409.15	460469.38	30.00	2.825	Bgy. 15, Poblacion
FB-8	937673.09	460308.64	10.00	2.482	Bgy. 5, Poblacion
FB-10	937078.75	460431.09	20.00	1.673	Arroyo Creek
FB-11	936822.33	460187.26	30.00	1.661	Bgy. Carmen
FB-12	936336.07	460251.99	10.00	3.986	Bgy. Macasandig
FB-13	936397.26	459686.56	20.00	3.155	Bgy. Carmen
FB-14	934817.63	459825.01	20.00	5.110	Bgy. Macasandig
FP-1	938180.56	460324.78	1.70	1.607	Isla de Oro, Poblacion
FP-2	936307.84	460108.34	2.00	3.739	U/S from Paseo del Rio
FP-3	934629.73	459600.81	1.50	4.090	Cala-cala, Macasandig
FP-4	932368.96	459998.99	2.00	9.341	Isla Puntod, Macasandig

Source: JICA Survey Team

2.3.2 Standard Penetration Test (SPT) at Borehole

Consistent with the general geology of CDOR, one finds thick beds of alluvial deposits that extend to at least 40.0m, the maximum investigation depth. Presented hereunder as Figure 2.3.1 is the summary of in-situ and Standard Penetration Test (SPT) results from boreholes.

Source: JICA Survey Team

Figure 2.3.1 In-Situ and SPT Results from Boreholes

2.3.3 In-situ Investigation at Test Pits

In-situ findings on test pits, FP-1, FP-2 and FP-4, revealed that the uppermost 2.0 m. consist of alluvial sand mixed with organic and non-organic (plastic, etc.) debris. FP-3 showed abundant gravel with cobbles, having at least 75 mm. in diameter.

2.4 Results of Investigations

Results of Test Pits and Boring investigations are summarized in Data Book B.

2.4.1 Evaluation on SPT Results

Evaluation of Standard Penetration Test (SPT) results are made as described below.

Table 2.4.1 Evaluation of Standard Penetration Test (SPT) Results

Location of Bore-hole	Description
Section: L1 FB-1	**FB-1** is underlain predominantly by loose silty fine sand, with lenses of silt, from the surface down to 11.0m. Consistently high N values (N≥25) start at depth 32.0-40.0 m. in silty sand deposits. Presence of shell fragments starts at 15.0m and prevails down to the bottom of the borehole at 40.0m. Decayed wood is present intermittently throughout the entire 40.0m profile. Cobbles were not encountered.
Section: L1 FB-2	**FB-2** is an alternating sequence of sand and silt, generally loose (N<10) in the upper 16.0m and medium dense, thereafter. Traces of shell fragments are evidenced at shallow depths of 10.0m and prevail down to the bottom of the borehole at 30.0m. Decayed wood is present, intermittently, between 10.0-25.0m.
Section: R2 FB-4	The uppermost 15.0m of **FB-4** consists of loose medium to fine silty sand with traces of gravel. The succeeding layers of silty sand and sandy silt are characterized by N values consistently within the range of 10 to 28, with presence of decayed wood and shell fragments. Cobbles were not encountered.
Section: R2 FB-6	**FB-6** is underlain by loose sand and soft clayey silt. Decayed wood fragments are prominently present on top and within the clayey-silt layer. Shell fragments were also noticed at depth 10.0m.
Section: R2 FB-7	**FB-7** is an alternating sequence of very loose sand and very soft clayey silt from the surface down to depth 19.0m. There is a significant increase of N values (17≤N≤22) in the sand layer between 19.0-23.0m, but drops to an average of N=7 in the clayey silt layer at 23.0-30.0m. Decayed wood was consistently recovered between 15.0and 25.0m. It is in this borehole where shell fragments were encountered, starting at depth 14.0m and beyond.
Section: R2 FB-8	**FB-8** is underlain by loose sand and loose silt from 0.0 to 5.8m. This is followed by a 0.5m thick deposit of cobbles, then by 0.5m thick clayey silt with decayed wood. The bottom of the borehole (7.0-10.0m) is occupied by soft clay.
Section: R3 FB-10	**FB-10** starts with a 3.5m thick surface deposit of soft clayey silt followed by loose sand that extends to depth 7.5m. Then a thick deposit of cobbles with gravel obtains at depth 7.5-17.0m, followed by dense sand up to depth 20.0m.
Section: L3 FB-11	**FB-11** is characterized by an alternating sequence of silt and silty sand. SPT N values are generally low (N<10) at depth 0.0-12.0 m., but, suddenly increase to (24≤N≤46) in the gray sand deposit at depth 12.0-21.0 m. Thereafter, N-values drop to an average of 11 in a silt deposit overlain by decayed wood. Cobbles were not encountered in this borehole.
Section: R4 FB-1	Further upstream at **FB-12**, the sand-cobbles-sand sequence is evidenced in this borehole. The cobble w/ gravel layer is at depth 3.0-5.5m.
Section: L3 FB-13	At **FB-13**, there is a 2.0m thick surface deposit of brown loose, sandy silt, followed by predominantly medium to coarse silty sand to depth 12.0m. The next layer is a 3.5-m thick layer of very loose (0≤N≤3) sand and slightly plastic silt. The bottom layer consists of moderately plastic silt and sand with decayed wood fragments. Cobbles with gravel.
Section: R4 FB-14	At **FB-14,** there is a 6.5-m surface deposit of cobbles and boulders, mostly sub-angular in shape. The next layer is a thick deposit of dark gray, dense, medium to fine sand with fine to medium gravel which extends to depth 20.0m, the bottom of the borehole. Traces of decayed wood are present at the surface of the deposits. Cohesive materials were not encountered.

Source: JICA Survey Team

2.4.2 Laboratory Test Results and Evaluations

(1) Laboratory Test Results

Soil material sampling and corresponding laboratory tests were conducted based on the estimated contract work quantity. All laboratory tests were performed in general accordance with ASTM procedures and standards. Soil samples were subjected to index laboratory index tests (NMC, LL & PL, specific gravity of soil solids and sieve analysis). Soil classifications are as per the Unified Classification System (USC) of ASTM.

Selected undisturbed samples of soft clay were subjected to consolidation testing to determine the values of the following parameters:

- C_c (coefficient of compressibility),
- C_r (coefficient of recompression),
- p_c (pre-consolidation pressure) *

  * as shown with the void ratio (e) vs pressure (p) curve and the coefficient of consolidation ($c_{v)}$ vs void ratio (e) curve.

However, some tests were not able to be performed to the required quantity due to unavailable presence of appropriate sample for the particular test. For which, undisturbed sampling for Consolidation and Tri-axial Tests were undertaken only for cohesive soils. Unconsolidated-un-drained (UU) tri-axial compression tests were conducted on selected un-disturbed specimens to determine strength parameters c(cohesion) and ø (angle of internal friction). The laboratory test work sheets are compiled in Data Book B and are summarized in the final logs of the test pits and soil borings.

(2) Weak Foundation Improvement Works

1) Introduction

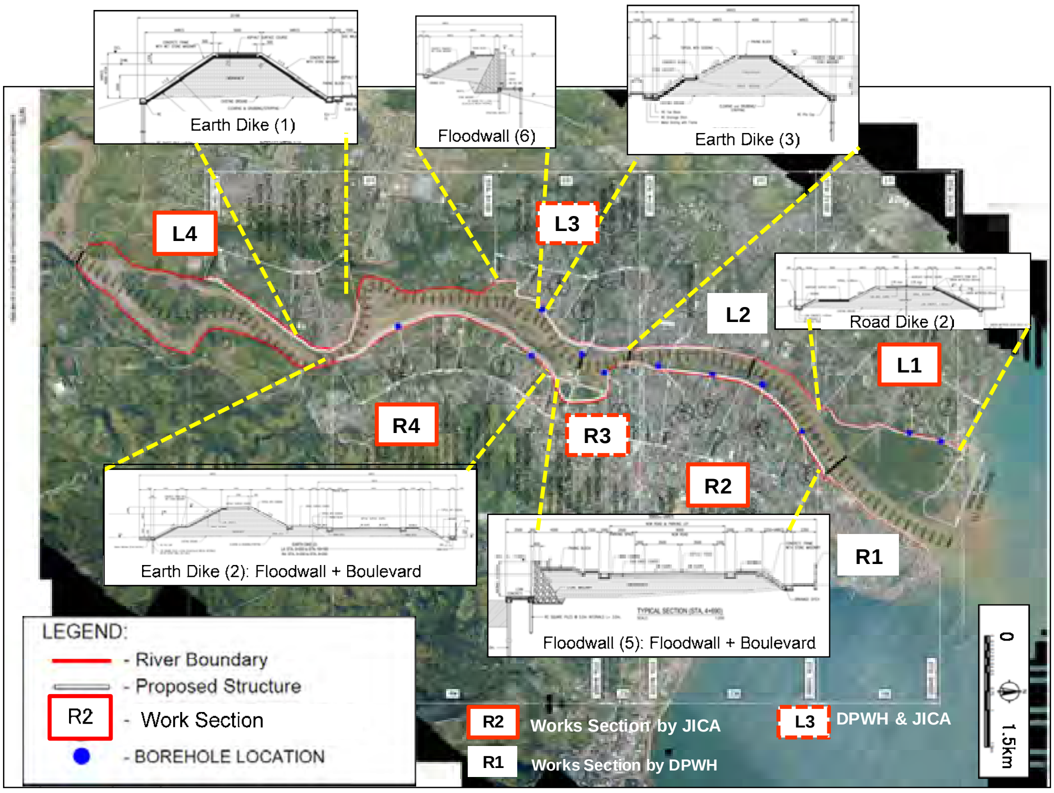
Proposed structures measures at each section are summarized in Table 2.4.2. Locations of the structure measures especially dike and flood wall along the CDOR are shown in Figure 2.4.1

Table 2.4.2 Structural Measures of the Priority Project at River Sections

	Section	Priority Project		Works by DPWH	Remarks Location (Barangay)
		Dike/Floodwall	Other Structures		
Left Bank	L1	- Road Dike (Earth Dike) - Floodwall + Earth-fill	- Slide Gates - Drainage outlet	—	Road Dike (Earth Dike): - Raising Existing Road - Evacuation Road (Bonbon, Kasuwangan)
	L2	—	—	Floodwall	DWPH's Urgent Works (Kasuwangan, Carmen)
	L3	- Earth Dike, - Floodwall	- Asphalt road - Gate and Drainage outlet - Kagay-an Bridge Improvement	Sheet Pile revetment	(COA office, Carmen) Low water channel revetment works are provided by DPWH's Urgent Works.
	L4	- Earth Dike, - Floodwall	- Asphalt road - Gates and Drainage outlet Works	—	(Carmen, Balulang)
Right Bank	R1	—	—	Concrete Dike	DWPH's Urgent Works (Puntod, Macabalang)
	R2	- Floodwall	- Asphalt road - Gates and Drainage outlet Works	Floodwall	(Consolacion, Pablacion)
	R3	- Floodwall - Earth Dike	- Gates and Drainage outlet Works	Floodwall (partial)	(Pablacion; City Hall & Cathedral) DWPH's Urgent Works will be made partially.
	R4	- Floodwall - Earth Dike	- Retarding Basin - Gates and Drainage outlet Works - Kagay-an Bridge Improvement	—	(Nazareth, Macasanding)

Source: JICA Survey Team

Location of major structures (Earth Dike and Floodwall), typical section and work sections are shown in Figure 2.4.1



Source: JICA Survey Team

Figure 2.4.1 Location of Structures (Earth Dike and Floodwall) and Work Section

2) Standard of Weak Foundation

Weak Foundation is classified based on N-value for technical evaluation of Settlement, Stability and Liquefaction

Weak foundation is standardized as described below and in Table 2.4.3.

- Clay foundation: N value (by SPT) < 4
- Sand foundation: N value (by SPT) < 10 to 15

Table 2.4.3 Classifications of Weak Foundation

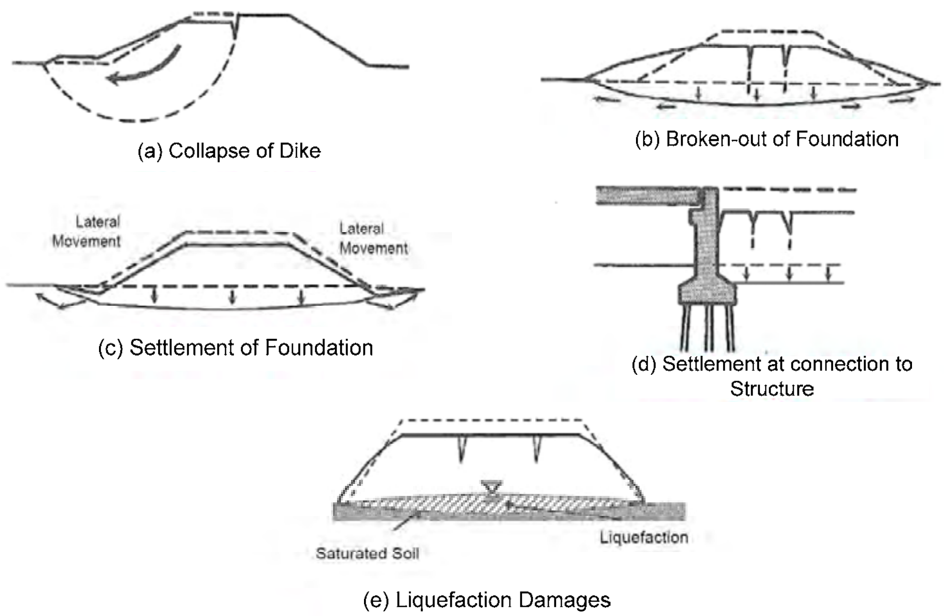
Geological Condition of Foundation	Thickness of Layer	Cohesion q_u (kg/cm^2)	N-value
Clay / Cohesive Clay	Less than 10m	C < 0.6	N < 4
	More than 10m	C < 1.0	N < 6
Sand / Sand Soil	-	0	N < 10 to 15

Source: JICA Survey Team

3) Damages by Weak Foundation

Damages of dike and bridge foundation due to weak foundation are shown in Figure 2.4.2.

(a) Collapse of Dike
(b) Broken-out of foundation
(c) Settlement of foundation
(d) Settlement at connection to structure (Bridge abutment)
(e) Liquefaction damages



Source: JICA Survey Team

Figure 2.4.2 Damages by Weak Foundation

3) Geological Conditions

i) Settlement

Summary of N-values of additional boring investigation are shown in Figure 2.3.1. Weak foundation layers are situated in the following locations of underneath. Foundation layers lower part, downstream of the Ysalina Bridge are determined to be composed of almost sandy soil in deep part of underneath (depth 0 to 30m).

Location of River Section (Boring Point)	Location in Depth (underneath)
- L1 (FB-1)	: 0 to 30m
- L1 (FB-2)	: 0 to 30m
- R2 (FB-4)	: 0 to 15m
- R2 (FB-7 & 8)	: 0 to 20m
- L3, R3, R4 (F-10, 11, 12, 13 and 14)	: 0 to 5-10m

Thick weak foundation layers of sandy soil (N<15) is estimated to be deposited in downstream part of the Cagayan de Oro River, sections L1, L2, R1 and R2. Settlements of the weak foundations are analyzed as shown in Table 2.4.4. More 50cm and 20-40cm settlements are estimated at L1 and R2 sections respectively.

Table 2.4.4 Settlement of the Weak Foundation

Boring Point (Section)	Immediate Settlement Sand Layer (cm)	Immediate Settlement Sand Soil Layer (cm)	Consolidation Settlement (cm)	Total Settlement (cm)
FB 2 (L1)	40.8	5.0	10.9	56.7
FB 4 (R2)	19.2	0.0	0.0	19.2
FB 7 (R2)	21.5	6.2	14.2	41.9

Source: JICA Survey Team

ii) Liquefaction

The following two examination methods are applied for judgment of liquefiable foundation as shown in Table 2.4.5. The two methods require for soil properties data for the examination. At first foundation soil properties are checked by the three (3) conditions of Method-1 mentioned below preliminary. In the next step, possibility of the liquefaction on foundation should be check by Method-2, liquefaction resistivity (F_L) method using of specified formula based on results of laboratory tests. When Liquefaction Resistivity is less than 1.0, the layer can be judged as liquefiable foundation.

Table 2.4.5 Liquefaction Judgment Methods

Method-1 (by soil properties data)	Method-2 (by Liquefaction Resistivity Formula)
a) Ground water level is within 10m from ground surface, and the soil layer is saturated and within 20m from ground surface. b) Fine fraction ratio (F_c) is more than 35%, or plasticity index (I_p) is lower than 15. c) Mean particle diameter (D_{50}) is lower than 10mm, and 10% particle diameter is lower than 1mm.	Liquefiable Soil : $F_L < 1.0$ $F_L = R/L$ $R = C_W \cdot R_L$ $L = r_d \cdot k_h \cdot (\sigma_v/\sigma_v')$ $r_d = 1.0 - 0.015x$ where: F_L : Liquefaction resistivity R : Dynamic shear rigidity ratio L : Shear stress ratio during earthquake C_W : Correction coefficient depending on seismic movement characteristics R_L : Cyclic triaxial strength ratio r_d : Reduction coefficient of depth direction during earthquake k_h : Design horizontal seismic intensity σ_v : Total stress at the depth of x(m), kN/m^2 σ_v' : Effective stress at the depth of x(m), kN/m^2 x : Depth from ground surface,(m)

Source: JICA Survey Team

In judgment by Liquefaction Resistivity (F_L) formula, the following seismic conditions and its coefficient are applied as shown in Table 2.4.6.

Table 2.4.6 Adopted Seismic Intensities

Seismic Movement		Ground Classification in Classification -2
Level-1: Seismic Movement		0.15
Level-2: Seismic Movement	Type-1	0.35
	Type-2	0.70

Source: JICA Survey Team

Results of liquefaction judgment by method-1 and 2 are summarized in Figure 2.4.3, in which Liquefiable on each target foundation layer (High / Low / unknown) is evaluated by the following criteria.

Table 2.4.7 Criteria of Liquefaction Judgment (Method-1)

Check Item of Method-1	Judgment on Liquefiable		
	High	Low	unknown
a) Ground water level is within 10m from ground surface, and the soil layer is saturated and within 20m from ground surface.	Applicable	Not applicable in one or two items of a), b), and c)	Not available on soil data
b) Fine fraction ratio (F_c) is more than 35%, or plasticity index (I_p) is lower than 15.	Applicable		
c) Mean particle diameter (D_{50}) is lower than 10mm, and 10% particle diameter is lower than 1mm.	Applicable		

Source: JICA Survey Team

FB2 GWL = 0.48m

No.	Depth (m)	Thickness (m)	Method-1 Liquefiable	Method-2 Level 1 liquefaction resistivity FL	Method-2 Level 2 type I liquefaction resistivity FL	Method-2 Level 2 type II liquefaction resistivity FL
1	0 1 2 3 4	4	High	0.5	0.2	0.1
2	5 6	2	High	3.9	1.7	0.8
3	7 8 9 10	4	Low	1.3	0.5	0.6
4	11 12	2	unknown	1.0	0.4	0.4
5	13 14 15 16	4	High	1.2	0.5	0.5
6	17 18 19 20	4	Low			

Sand / SiltySand / Sandy Silt / Cleyey Silt / Clay

FB4 GWL = 0.9m

No.	Depth (m)	Thickness (m)	Method-1 Liquefiable	Method-2 Level 1 liquefaction resistivity FL	Method-2 Level 2 type I liquefaction resistivity FL	Method-2 Level 2 type II liquefaction resistivity FL
1	0 1 2	2	High	8.3	3.5	1.8
2	3 4 5 6 7 8	6	High	1.1	0.5	0.4
3	9	1	High	34.4	14.7	7.4
4	10 11 12 13	4	High	1.2	0.5	0.5
5	14 15	2	unknown	91.6	39.2	19.6
6	16 17 18	3	unknown	5.3	2.3	1.1
7	19	1	Low	-	-	-
8	20	6	Low	-	-	-

FB7 GWL = 2.1m

No.	Depth (m)	Thickness (m)	Method-1 Liquefiable	Method-2 Level 1 liquefaction resistivity FL	Method-2 Level 2 type I liquefaction resistivity FL	Method-2 Level 2 type II liquefaction resistivity FL
1	0 1 2 3	3	Low	1.7	0.7	0.5
2	4 5 6 7 8	5	High	1.0	0.4	0.3
3	9 10 11 12	4	Low	1.2	0.5	0.4
4	13 14 15 16 17 18 19	7	High	1.2	0.5	0.4
5	20	4	High	2.2	0.9	1.0

FB11 GWL = 2.1m

No.	Depth (m)	Thickness (m)	Method-1 Liquefiable	Method-2 Level 1 liquefaction resistivity FL	Method-2 Level 2 type I liquefaction resistivity FL	Method-2 Level 2 type II liquefaction resistivity FL
1	0 1 2	2	Low	1.8	0.8	0.7
2	3 4 5 6	4	unknown	-	-	-
3	7 8 9 10 11 12 13	7	Low			
4	14 15 16 17 18 19 20	7	High	19.0	8.1	4.1

Gravel &Cobble / Sand / SiltySand / Sandy Silt / Cleyey Silt / Clay

FB13 GWL = 3.3m

No.	Depth (m)	Thickness (m)	Method-1 Liquefiable	Method-2 Level 1 liquefaction resistivity FL	Method-2 Level 2 type I liquefaction resistivity FL	Method-2 Level 2 type II liquefaction resistivity FL
1	0 1 2	2	Low	3.3	1.4	1.6
2	3 4 5	3	unknown	1.4	0.6	0.4
3	6 7 7.5	2.5	unknown	-	-	-
4	8	0.5	unknown	-	-	-
5	9 10 11 12	4	unknown	3.8	1.6	2.7
6	13 14 15	3	High	0.7	0.3	0.2
7	16 17 18 19 20	5	Low	0.7	0.3	0.2

FB14 GWL = 3.66m

No.	Depth (m)	Thickness (m)	Method-1 Liquefiable	Method-2 Level 1 liquefaction resistivity FL	Method-2 Level 2 type I liquefaction resistivity FL	Method-2 Level 2 type II liquefaction resistivity FL
1	0 1	1	unknown	-	-	-
2	2 3 4 5 6 6.5	5.5	unknown	-	-	-
3	7 8 9 10 11 12 13	6.5	High	14.7	6.3	3.1
4	14 15 16 17 18 19 20	7	High	8.6	3.7	1.9

Source: JICA Survey Team

Figure 2.4.3 Results of Liquefaction Judgment

4) Weak Foundation Measures

According to geological condition of the project sites, applicable weak foundation improvement works for the project sites, Sand Compaction Piling Work (SCP) and Cement Deep mixing Work (CDM) are summarized in Table 2.4.8.

Table 2.4.8 Summary of Weak Foundation Improvement (SCP and CDM)

Weak Foundation Improvement Works	Applicable Foundation Type	Matter of Prevention / Reduction against Weak Foundation		
		Settlement	Sliding / Collapse	Liquefaction
Sand Compaction Piling Work (SCP)	Sandy Soil	Effective	Effective	Effective
Cement Deep mixing Work (CDM)	Silt	Effective	Effective	Not applicable

Source: JICA Survey Team

Sand Compaction Piling Work (Static Type of SCP) is proposed to be provided along the Burgos Street (R2) for river structure; Retaining Wall + Embankment as weak foundation improvement works in technical, Environment and Economic reasons. Design Standards and design dimensions are described as below

i) Safety Factors

a) Normal Condition Fn = 1.2
b) Seismic Condition Fs = 1.0
c) Flood Condition Ff = 1.2

ii) Seismic Load

A seismic coefficient equal to one – half the acceleration coefficient (Kh = A/2) is adopted. Therefore, the value at the project area is computed as follows:

K_h = 0.40 / 2 = 0.20
A : Acceleration coefficient (A = 0.40)
K_h : Seismic coefficient used to calculate lateral earth pressures and defined above

Weak Foundation Improvement Works are summarized in Table 2.4.9, from which weak foundation improvement works are not required in sections; L3, R3, L4, R4.

Table 2.4.9 Weak Foundation Improvement for Structures and its Locations

Section	Station	Structural Measure	Weak Foundation Improvement
L1	Sta. 0+000 to Sta. 2+100	Road Dike (Earth Embankment)	Pre-Loading Method L=2,600m
R2	Sta. 1+500 to Sta. 4+220	Retaining wall + Embankment	Sand Compaction Piling Works (SCP) L= 2,100m
L3	Sta. 4+220 to Sta. 6+100	Earth Dike Retaining wall	Not applied
R3	Sta. 4+220 to Sta. 4+600	Earth Dike	Not applied
L4	Sta. 6+100 to Sta. 10+100	Earth Dike Retaining wall	Not applied
R4	Sta. 4+600 to Sta. 8+500	Earth Dike	Not applied

Source: JICA Survey Team

Design dimensions of Sand Compaction Improvement Works at R2 section are described as below.

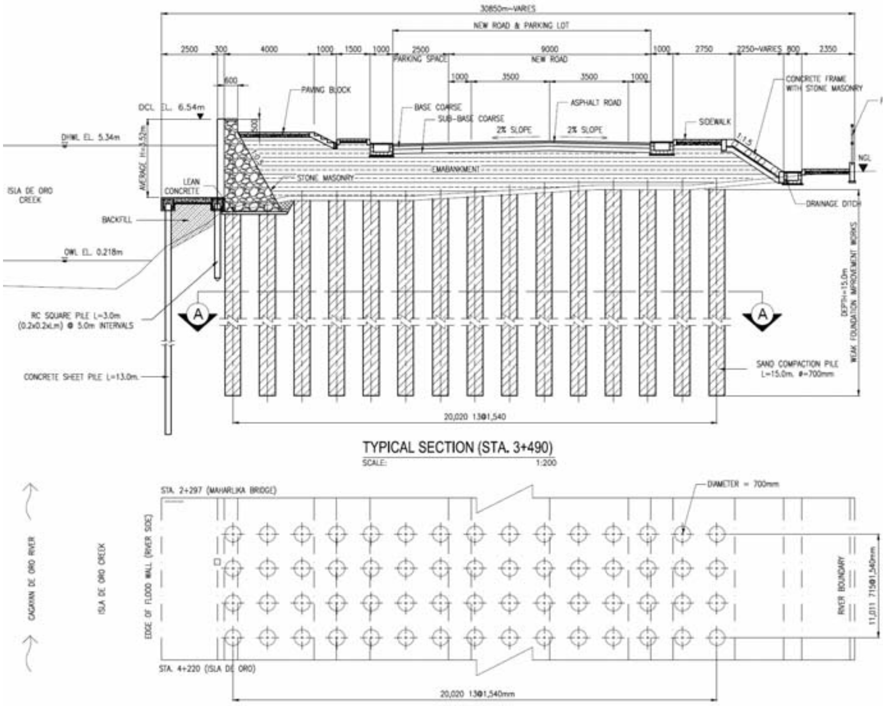
Sta. 1+880 – 2+980:

- Diameter of Pile : 0.7m
- Intervals of Piling : 2.4m
- Width of Piling Works : 20.0m
- Depth of Piling : 10.0m

Sta. 2+980 – 4+220:

- Diameter of Pile : 0.7m
- Intervals of Piling : 1.5 m
- Width of Piling Works : 20.0m
- Depth of Piling : 15.0m

Typical Section and Plan of Structural Measure and Weak Foundation Improvement Works at Sta. 2+980 – 4+220 is shown in below, Figure 2.4.4.



Source: JICA Survey Team

Figure 2.4.4 Typical Design of Floodwall with Boulevard and Sand Compaction Pile (SCP) in R2 section

(3) Liquefaction Mitigating Measures

Scour and liquefaction are probably the most serious soil related issues in the design of flood control structures at the project site.

Most soils at the project site, being alluvial in nature, are subject to scour. A specialized study will have to be carried out to determine the extent of scouring, depth and its effect on proposed dikes and appurtenant structures.

Being underlain by saturated, cohesion-less, sand and silt, the sub-soils at the borehole locations, are susceptible to liquefaction. Exceptions to this are FB-10 and FB-14, which are regarded as non-liquefiable.

Table 2.4.10 Recommended Liquefaction Mitigating Measures

Boring No.	Proposed Structure	Base Materials	Foundation Recommendation
FB-1	Culvert	Removable 1.0m thick surface silt followed by loose liquefiable sand. Because of the thickness of liquefiable zone soil improvement may not be cost effective as driven piles	Use Driven Pile Foundation
FB-2	Evacuation Road/Dike	Loose, highly liquefiable sand (0.0-4.0m) followed by medium dense sand then by non-liquefiable material (6.0-10.0m)	Sand columns: 0.0-4.0m.
FB-4	Dikes	Loose, liquefiable sand (0.0-15.0m)	0.0-5.0m should be rendered non-liquefiable by sand columns which will also increase the bearing capacity of the sub-soils
FB-6	Sluice Gates	Loose, liquefiable sand (0.0-10.0m)	0.0-5.0m should be rendered non-liquefiable by sand columns which will also increase the bearing capacity of the sub-soils
FB-7	Dikes	Loose, liquefiable sand (0.0-8.0m)	0.0-5.0m should be rendered non-liquefiable by sand columns which will also increase the bearing capacity of the sub-soils
FB-8	Sluice Gates	Loose, liquefiable sand (0.0-6.0m)	0.0-6.0m should be rendered non-liquefiable by sand columns which will also increase the bearing capacity of the sub-soils
FB-10	Sluice Gates	0.0-3.0m is non-liquefiable.	Unless it is established by detailed investigation that this is extensive, soil improvement up to 8.0m is recommended. Short piles with depths of 8.0m BGL may also be used
F-11	Bridge	Loose, liquefiable sand (0.0-6.0m)	Piles should be used as bridge foundation. Depending on the required capacity the piles should be placed at depths between 13.0 to 21.0m. For the approach embankment, 0.0-6.0m should be rendered non-liquefiable by sand columns which will also increase the bearing capacity of the sub-soils.
FB-12	Dikes	Loose, liquefiable sand (0.0-1.0m)	Soil improvement by surface compaction would be adequate
FB-13	Sluice Gates	Loose highly liquefiable sand from 0.0-5.0, moderately liquefiable from 5.0-7.5m.	0.0-5.0m should be rendered non-liquefiable by sand columns which will also increase the bearing capacity of the sub-soils
FB-14	Dikes	Loose, liquefiable sand (0.0-1.0m)	Soil improvement by surface compaction would be adequate

Source: JICA Survey Team

Supporting Report
Appendix C
Meteorological and Hydrological Survey

PREPARATORY SURVEY
FOR
FLOOD RISK MANAGEMENT PROJECT
FOR
CAGAYAN DE ORO RIVER (FRIMP-CDOR)
IN
THE REPUBLIC OF THE PHILIPPINES

FINAL REPORT

VOLUME III SUPPORTING REPORT (I)

Appendix C Rainfall and Run-Off Analysis

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CHAPTER 1 GENERAL

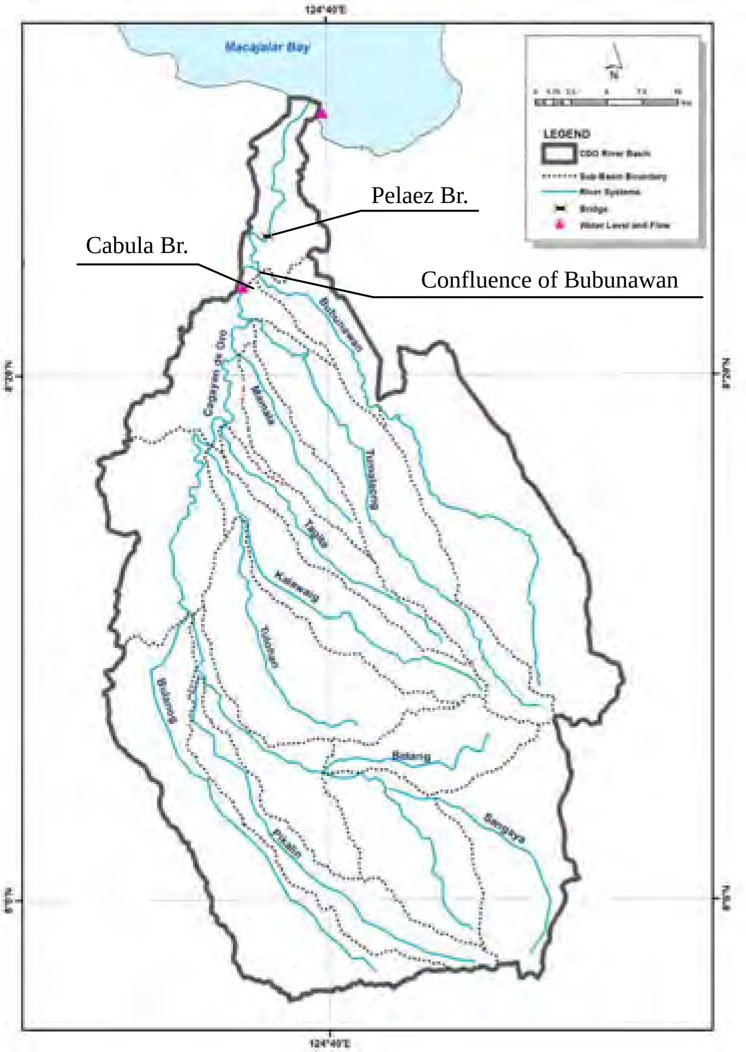
1.1 Objective Area

Objective area of the hydrologic and hydraulics analyses is the whole Cagayan de Oro(CDO) River Basin located in the Northern Mindanao Island including the periphery of the basin where related hydrological information are available.

The basin is bounded on the south by the Kalatungan Mountains, on the east by the Katanglad Mountains and on the west by an unidentified mountain range.

1.2 River Network, Flood Plain and Catchment

The Cagayan de Oro River has its headwaters in the Kalatungan Mountain Range found in the central part of the province of Bukidnon. It traverses the Municipalities of Talakag, Baungon and Libona, picking up tributaries along the way in a generally northerly direction towards the city of Cagayan de Oro passing a flood plain section of the river before it finally empties into the Macajalar Bay.



Source: JICA Survey Team

Figure 1.2.1 Cagayan de Oro River Basin

Cagayan de Oro River has a catchment area of approximately 1,364 km^2 where the major part is located in the Province of Bukidnon and the rest is within the Province of Misamis Oriental. The Cagayan de Oro River, as main stream, forms the Cagayan de Oro River Basin with eight (8) major tributaries, namely; Batang, Bubunawan, Bulanog, Kalawig, Picalin, Tagait, Tumalaong Rivers, and Lapinigan Creek, Cagayan de Oro River Basin as shown in Figure 1.2.1.

1.3 Analyses

The rainfall and runoff analyses were undertaken for a whole CDO River basin. In particular, the rainfall analysis is targeting at a whole basin, while the runoff analysis is made so as to obtain the discharge hydrograph at the Pelaez Bridge point which is about 12.0 km upstream from the river mouth as shown in Figure 1.2.1.

The downstream river section to the river mouth was analyzed through the flood inundation analysis with unsteady flow as well as the riverbed fluctuation analysis, for which the discharge hydrograph at the Pelaez Bridge is to be given as an upstream boundary condition.

CHAPTER 2 HYDRO-METEOROLOGICAL DATA

2.1 Rainfall

There are 73 rainfall stations in and around the CDO River basin of which data are available for the analysis in this Survey including those under Del Monte Philippine Inc, PAGASA Synoptic stations, Department of Agriculture(DA) Agromet stations, DA-Municipal Agriculture Office (MAO) in LGUs., DA-BSWM and PALASAT (private firm) as shown in Table 2.1.1. Most stations contain daily rainfall data and hourly data are available at only a few stations for the short recent period as shown in Table 2.1.2.

Table 2.1.1 Rainfall Data and Availability

Type of Data	Data Source	Nos. Of Station	Availability during TS Sendong
Daily Rainfall	PAGASA Synoptic Station	9 (*1)	3 (*2)
	Del Monte Station	45	34 (*2)
	DA agromet station	2	1 (*2)
	DA-BSWM	1	- (*2)
	DA-MAO	3	2 (*2)
	Sub Total	60	40 (*2)
6-hour Rainfall	PAGASA Synoptic Station	(4) (*1)	3
	PAGASA Synoptic Station	2	-
	Sub Total	(4)+2	3
Hourly Rainfall	PAGASA ARG Station (*3)	9	9
	PALASAT Digital Station	2	1
	Sub Total	11	10
	Grand Total	73	53

Note: (*1) 6-hour rainfall record are available at four(4) PAGASA synoptic stations except El Salvador and Hinatuan stations out of the nine(9) where daily rainfall record are available.

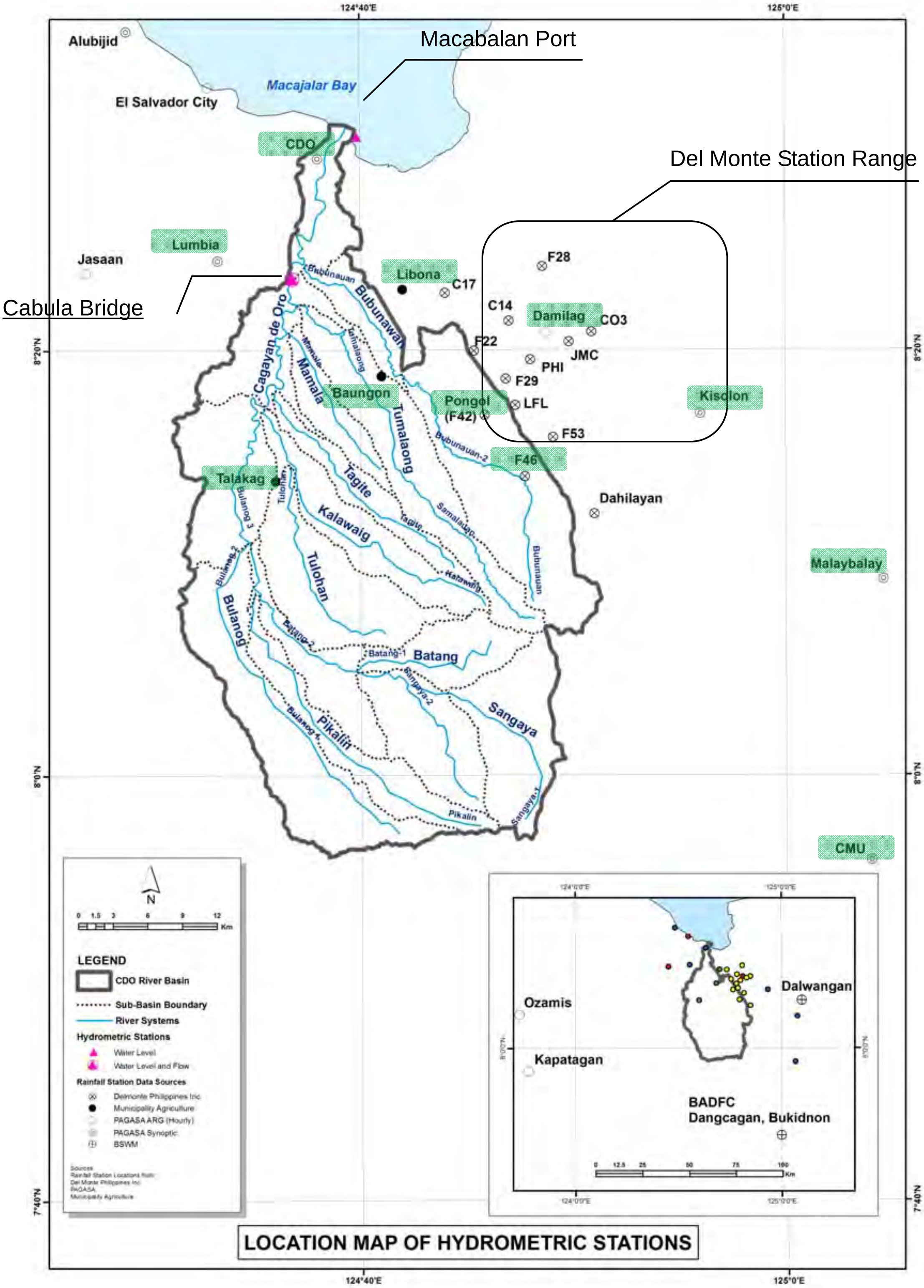
(*2) Number of stations where complete daily rainfall data are available in 2012.

(*3) PAGASA Automatic Rain Gauge (ARG) station.

Source: JICA Survey Team

Locations of those available stations are presented in Figure 2.1.1. Data available period of the respective stations are shown in Table 2.1.2, respectively, together with the inventory of the stations.

Out of 60 stations of daily rainfall stations, the annual rainfall record at Kisolon, Lumbia, Malaybalay and Cagayan de Oro, which has long-term record available, are shown in Table 2.1.3.



Source: JICA Survey Team

Figure 2.1.1 Location Map of Hydrometric Stations

Note : Most of the observation stations, excluding those far from the CDO River basin, are shown in the figure above including all stations selected for further analysis. However, many observation stations operated by the Del Monte Philippines are concentrated in a limited area, only representing stations are shown above.

Stations with hatching show the selected rainfall stations as listed in Table 3.2.1.

Table 2.1.2 Available Rainfall and Waterlevel Stations (1/3)

1-1 Hourly Rainfall (1-hour)

No.	Station	Location		Elevation	Data	Source
		Longitude	Latitude	(El., m)	Available Period	
1	Cagayan de Oro	N08° 29’ 00”	E124° 38’ 00”	6	2012	PARASAT Digital
2	Dahilayan	N08° 12’ 36”	E124° 51’ 00”		16 - 17 Dec 2011	PARASAT Digital
3	Damilag	N08° 23’ 00”	E124° 47’ 00”	591	16 - 17 Dec 2011	PAGASA ARG
4	Talakag	N08° 13’ 48”	E124° 36’ 00”	404	16 - 17 Dec 2011	PAGASA ARG
5	Jasaan	N08° 23’ 24”	E124° 27’ 00”		16 - 17 Dec 2011	PAGASA ARG
6	Kapatagan	N07° 53’ 24”	E124° 46’ 19”	15	16 - 17 Dec 2011	PAGASA ARG
7	Moscat				16 - 17 Dec 2011	PAGASA ARG
8	Hinatuan				15 - 17 Dec 2011	PAGASA ARG
9	Butuan	N08° 56’ 00”	E125° 31’ 00”	18	15 - 16 Dec 2011	PAGASA ARG
10	Ozamis	N08° 09’ 36”	E123° 43’ 48”		16 - 17 Dec 2011	PAGASA ARG
11	Phillips	N08° 19’ 48”	E124° 48’ 00”		16 - 17 Dec 2011	PAGASA ARG

Source: JICA Survey Team

1-2 Hourly Rainfall (6-hour)

No.	Station	Location		Elevation	Data	Source
		Longitude	Latitude	(El., m)	Available Period	
1	Lumbia	N08° 26’ 00”	E124° 37’ 00”	182	1976-2012	PAGASA Synoptic
2	El Salvadar City	N08° 32’ 24”	E124° 33’ 00”		Apr. & Jun. 2012	PAGASA Synoptic
3	Malaybalay	N08° 09’ 07”	E125° 07’ 37”	603	1961-2012	PAGASA Synoptic
4	Butuan	N08° 56’ 00”	E125° 31’ 00”	18	1980-2010	PAGASA Synoptic
5	CDO	N08° 29’ 00”	E124° 38’ 00”	6	1961-2009	PAGASA Synoptic
6	Hinatuan				1961-2012	PAGASA Synoptic

Source: JICA Survey Team

Table 2.1.2 Available Rainfall and Waterlevel Stations (2/3)

2. Daily Rainfall (1/2)

No.	Station	Location		Elevation (El., m)	Data Available Period	Source
		Longitude	Latitude			
1	Lumbia	N08° 26' 00"	E124° 37' 00"	182	1977 – 2012	PAGASA Synoptic
2	Kisolon	N08° 17' 00"	E124° 56' 00"	675	1980 – 2006	PAGASA Synoptic
3	Malaybalay	N08° 09' 07"	E125° 07' 37"	603	1949 – 2011	PAGASA Synoptic
4	CDO	N08° 29' 00"	E124° 38' 00"	6	1950 – 2000	PAGASA Synoptic
5	Alubjid	N08° 35' 00"	E124° 29' 00"	33	1980 – 2006	PAGASA Synoptic
6	CMU	N07° 56' 00"	E125° 04' 00"	412	1980 – 2012	PAGASA Synoptic
7	Damilag	N08° 23'00"	E124°47' 00"	591	1967 – 1984	PAGASA Synoptic
8	Kapatagan	N08° 53' 24"	E123° 46' 19"	15	1991 – 2006	PAGASA Synoptic
9	Butuan	N08°56' 00"	E125° 31' 00"	18	1981– 2000	PAGASA Synoptic
10	Talakag	N08° 13' 48"	E124° 36' 00"	404	2006 – 2012	Municipality Agriculture
11	Libuna	N08° 22' 50"	E124° 42' 00"	309	2006 - 2012	Municipality Agriculture
12	ALU				2006 - 2012	Delmonte Philippine Inc
13	BAL				2003 - 2012	Delmonte Philippine Inc
14	BUL				2005 - 2011	Delmonte Philippine Inc
15	C14	N08° 21' 36"	E124° 46' 48"		1992 - 2012	Delmonte Philippine Inc
16	C17	N08° 22' 48"	E124° 43' 48"		1992 - 2012	Delmonte Philippine Inc
17	CAT				2005 - 2012	Delmonte Philippine Inc
18	CLA				2010 - 2011	Delmonte Philippine Inc
19	C03	N08° 20' 52"	E124° 50' 54"	601	1992 - 2012	Delmonte Philippine Inc
20	DIC				2010 - 2012	Delmonte Philippine Inc
21	ELS				2005 - 2012	Delmonte Philippine Inc
22	F22	N08° 19' 58"	E124° 45' 21"	626	1999 - 2012	Delmonte Philippine Inc
23	F28	N08° 24' 00"	E124° 48' 36"		2004 - 2012	Delmonte Philippine Inc
24	F29	N08° 17' 25"	E124° 47' 18"	751	1999 - 2012	Delmonte Philippine Inc
25	F46	N08° 14' 04"	E124° 47' 44"	736	2004 - 2012	Delmonte Philippine Inc
26	F53	N08° 16' 12"	E124° 49' 12"		1999 - 2012	Delmonte Philippine Inc
27	F70	N08° 19' 48"	E124° 54' 36"		1999 - 2012	Delmonte Philippine Inc
28	F75	N08° 18' 00"	E124° 55' 12"		1992 - 2012	Delmonte Philippine Inc
29	F79	N08° 15' 00"	E124° 54' 36"		1998 - 2012	Delmonte Philippine Inc
30	F80	N08° 22' 48"	E124° 55' 12"		2002 - 2012	Delmonte Philippine Inc
31	F81	N08° 24' 00"	E124° 58' 12"		2002 - 2012	Delmonte Philippine Inc
32	F82	N08° 19' 12"	E124° 54' 36"		1992 - 2012	Delmonte Philippine Inc
33	F83	N08° 16' 48"	E124° 54' 36"		2005 - 2011	Delmonte Philippine Inc
34	F85				1992 - 2012	Delmonte Philippine Inc
35	F86	N08° 11' 24"	E125° 02' 24"		1992 - 2012	Delmonte Philippine Inc
36	F88				1997 - 2011	Delmonte Philippine Inc
37	F89	N08° 08' 24"	E125° 04' 12"		1998 - 2011	Delmonte Philippine Inc
38	F90				1997 - 2012	Delmonte Philippine Inc
39	F93				2005 - 2012	Delmonte Philippine Inc
40	F94				2004 - 2012	Delmonte Philippine Inc

Source: JICA Survey Team

Table 2.1.2 Available Rainfall and Waterlevel Stations (3/3)

2. Daily Rainfall (2/2)

No.	Station	Location		Elevation (El., m)	Data Available Period	Source
		Longitude	Latitude			
41	F96				2006 - 2012	Delmonte Philippine Inc
42	JMC	N08° 20' 24"	E124° 49' 24"	628	1992 - 2012	Delmonte Philippine Inc
43	KAB				2010 - 2011	Delmonte Philippine Inc
44	KIA				2009 - 2012	Delmonte Philippine Inc
45	KUL				2010 - 2011	Delmonte Philippine Inc
46	LAG				2003 - 2012	Delmonte Philippine Inc
47	LFL	N08° 18' 39"	E124° 46' 51"	723	1992 - 2012	Delmonte Philippine Inc
48	LIB				2010 - 2012	Delmonte Philippine Inc
49	NAB				2010 - 2012	Delmonte Philippine Inc
50	PAG				2005 - 2012	Delmonte Philippine Inc
51	PAT				2010 - 2011	Delmonte Philippine Inc
52	PHI	N08° 19' 48"	E124° 48' 00"		1992 - 2012	Delmonte Philippine Inc
53	PONGOL(F42)	N08° 16' 48"	E124° 45' 36"	706	1992 - 2012	Delmonte Philippine Inc
54	SAM				2005 - 2011	Delmonte Philippine Inc
55	SAN				1992 - 2012	Delmonte Philippine Inc
56	STA				2003 - 2012	Delmonte Philippine Inc
57	Dalwangan	N08° 13' 48"	E125° 06' 00"	866	2002 - 2012	Dept. of Agriculture
58	Claveria				2002 - 2012	Dept. of Agriculture
59	BAFC Dangcagan	N07° 39' 40"	E124° 59' 58"	370	1994 - 2011	Bureau of Soils and Water Management
60	Baungon	N08° 18' 46"	E124° 41'00"	404	2005- 2011	Municipality Agriculture

Source: JICA Survey Team

3. Daily Evaporation

No.	Station	Location		Elevation (El., m)	Data Available Period	Source
		Longitude	Latitude			
1	Dalwangan	N08° 13' 42"	E125° 05' 57"	866	2009 - 2012	Dept. of Agriculture
2	CMU	N07° 56' 00"	E125° 04' 00"	412	2010 - 2011	PAGASA Synoptic
3	PHI	N08° 19' 48"	E124° 48' 00"		2003 - 2012	Delmonte Philippine Inc

Source: JICA Survey Team

4. Water Level and Discharge Measurement

No.	Station	Location		Elevation (El., m)	Data Available Period	Source
		Longitude	Latitude			
1	Macabalan Port	N08° 30' 48"	E124° 40' 12"		(6-hr, predicted) 2008 (hourly Tidal WL) Nov-Dec 2007, 2008, Jun-Dec 2009, Jan-Aug 2010, Mar-Dec 2011, Jan-Mar 2012	NAMRIA
2	Cabula BR			39.70	1991 - 2012	DPWH

Source: JICA Survey Team

Table 2.1.3 Annual Rainfall Record

Year	Kisolon (mm)	Lumbia (mm)	Malaybalay (mm)	Cagayan de Oro (mm)
1961			2,206	1,500
1962			2,894	1,631
1963			3,010	1,543
1964			2,762	1,920
1965			2,852	2,016
1966			2,884	1,513
1967			2,080	1,663
1968			2,040	1,415
1969			2,001	1,109
1970			2,229	1,543
1971			2,819	1,973
1972			2,526	1,510
1973			2,339	2,040
1974			2,912	1,728
1975			3,473	1,996
1976			2,003	1,138
1977		1,408	2,112	1,491
1978		1,553	2,334	1,659
1979		1,394	2,416	1,271
1980		1,903	2,695	1,609
1981	1,364	1,498	2,341	1,568
1982	1,134	1,618	2,348	1,363
1983	1,277	1,467	2,434	1,331
1984	1,179	1,489	2,715	1,748
1985	1,248	1,851	2,692	1,933
1986	1,497	1,603	2,641	1,664
1987	563	1,116	2,564	1,120
1988	785	1,583	2,654	1,541
1989	688	2,108	2,990	1,799
1990	729	1,961	2,215	1,718
1991	702	1,437	1,949	1,170
1992	509	1,221	2,559	1,218
1993	1,324	1,854	2,519	1,406
1994	998	1,784	2,216	1,561
1995	1,284	1,884	3,143	1,725
1996	1,833	1,817	2,271	1,429
1997	1,070	1,644	2,830	1,281
1998	847	1,353	1,865	1,039
1999	1,608	2,340	3,655	2,187
2000	1,042	2,125	3,147	1,840
2001	1,516	2,031	2,674	2,094
2002	982	1,723	2,005	1,394
2003	1,188	1,959	2,973	1,855
2004	1,005	1,259	2,174	
2005	946	1,630	2,386	1,707
2006	938	1,411	2,020	1,214
2007		1,666	2,798	1,614
2008		2,162	2,986	
2009		2,564	3,001	
2010		1,794	2,836	
2011		2,188	3,753	
2012		2,798	3,047	
Average	1,087	1,755	2,596	1,582

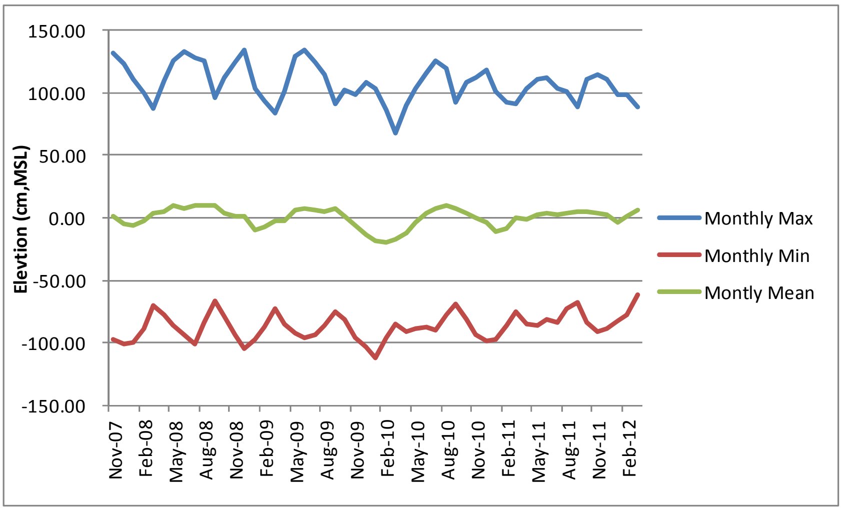
Source: JICA Survey Team

2.2 Water Level and Discharge

There is only one regular water level and flow observation station maintained by DPWH located at the Cabula Bridge(C.A.=1,094km^2) in the CDO River. The water level and discharge data for the period from 1991 to October 2012 are available by the DPWH Region-10 office in the Cagayan de Oro City.

Tidal water levels of the Macajalar Bay at the Macabalan Port are available in NAMRIA. The inventory of water level and discharge gauging stations is shown in Table 2.1.2.

Tidal water level for the CDO port is vertically referenced to the mean sea level as mentioned NAMRIA data sheet shown in Figure 2.2.1.



Source: NAMRIA

Figure 2.2.1 Tide Level at Macabalan Port (2007-2011)

2.3 Hydro-meteorological Data

(1) Evaporation

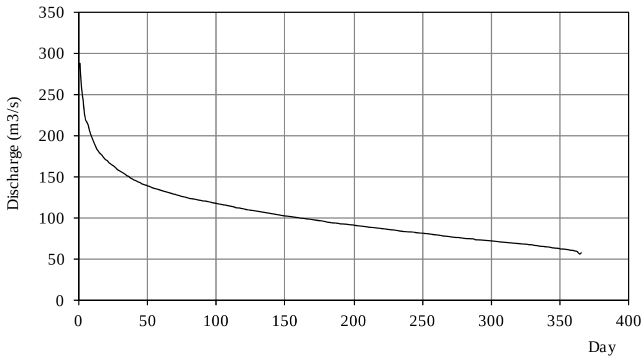
There are three pan evaporation stations available nearly outside boarder of the CDO River basin. The list of evaporation data stations are shown in Table 2.1.2.

(2) Groundwater Depth and Irrigation/Abstraction Data

There were no information and data available regarding observation of groundwater depth and irrigation abstraction in the study area. In several meetings with DA and PAGASA, the issue has been raised and informed that they usually do not maintain such ground water monitoring/recording station so far.

(3) Discharge-Duration Curve

Discharge-duration curve is shown in Figure 2.3.1. This discharge was calculated based on the observed daily discharge record at the Cabula Bridge compiled in "Stream Flow Data", Cagayan River Stream Gauging Station (2011) prepared by Materials Quality Control & Hydrology Division, DPWH Region-10, recording daily water level from 1991 to 2011. This record is shown in Appendix P in DATA BOOK.



Source: JICA Survey Team

Figure 2.3.1 Discharge-Duration Curve (1991-2012 for 21years)

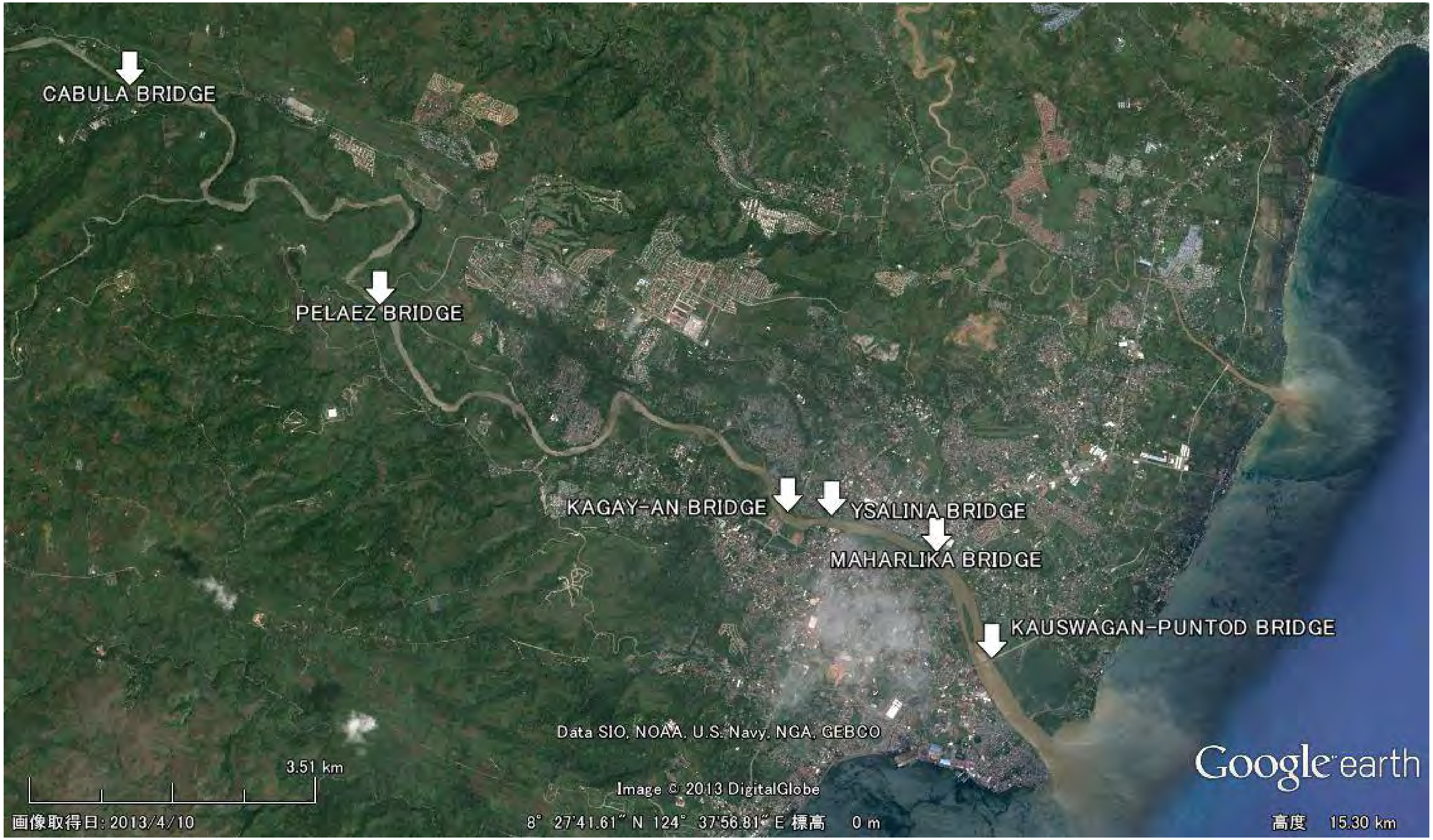
2.4 Topographic Data

(1) River Cross Section

The longitudinal and cross section survey of the CDO River were conducted under this Survey for FRIMP-CDOR. The survey have been conducted for about 12.0 km along the river stretch between the river mouth up to the location near Pelaez Bridge as shown in Figure 2.4.1. The total number of sections is 38 including five bridge locations.

National Mapping and Resource Information Authority(NAMRIA) control points having Philippine Transeverse Mercator(PTM) projection coordinated were used as horizontal reference. The NAMRIA's benchmarks taken from the mean sea level (MSL) of the Philippines served as its vertical reference.

Locations of the bridges are shown in Figure 2.4.1.

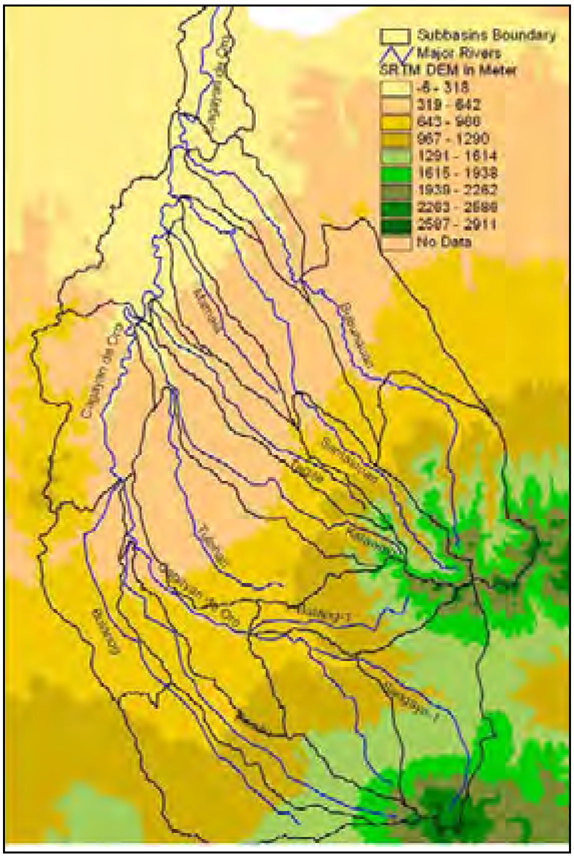


Source : JICA Survey Team

Figure 2.4.1 Locations of the Bridges

(2) Topographic Condition of the CDO River Basin

Topographic condition of the CDO River basin is indicated over the SRTM data as shown in Figure 2.4.2.



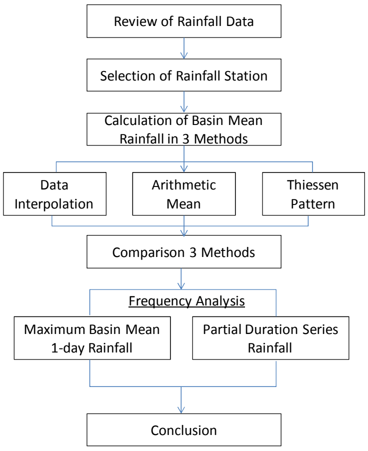
Source: SRTM DEM, NASA

Figure 2.4.2 Land Elevation in CDOR Basin using SRTM DEM

CHAPTER 3 Rainfall Analysis

3.1 Approach and Methodology of Rainfall Analysis

The study includes data collection, analyzing and checking of data, and analysis for rainfall. Figure 3.1.1 outlines the overall approach of rainfall analysis.



Source: JICA Survey Team

Figure 3.1.1 Flow of Rainfall Analysis

3.2 Selection of Rainfall Station

Among 60 stations where daily rainfall record are available as shown in Table 2.1.1, there are 45 Del Monte stations in addition to the other 15 stations.

(1) Selection out of Del Monte Stations

Observation at some of Del Monte stations were commenced from the middle of year 1992. Screening was made to select representative stations out of 45 Del Monte stations through the following manner:

	Selection	**Stations Remained**
(i)	Stations which has complete 20 year record (1993 through 2012) and location is definite	10 stations+F46(*1)
(ii)	Reliability check of record by Double Mass Curve(DMC) method(*2)	6 stations (*3) including F46(*1)
(iii)	Station(s) which location has an advantage to be a representing station in a Thiessen Polygon for estimate of basin mean rainfall among the selected stations through screening (i) and (ii)	PON(F42), F46(*1)

Notes (*1): F46 has a data available period of eight(8) yeas only(2005 – 2012), however F46 is remained due to remarkable record of 475 mm/day on December16, 2011 during TS. Sendong.

(*2): DMC sheets for combinations of all stations are compiled in Appendix P in DATA BOOK.

(*3): PON, LFL, PHI, F75, F86 and F46

(2) Other Stations

Out of 15 stations, the following six(6) stations were discarded; three (3) stations due to distant locations from the CDO River basin(more than 50 km from the edge of the basin boundary; Butuan, Dangcagan, Kapatan) ; no exact information of location(Calaveria) and no correlation with other stations(Alubujid). In addition, location of Dalwangan

Station has a disadvantage not to be a representing station in any Thiessen pattern due to other adjacent stations. Thus 9 stations (No.1 to No.9 in Table 3.2.1) were evaluated as the representing stations.

(3) Stations to be Used and Analysis Period

Daily rainfall data at several stations are available starting from early 1980’s, while, rather long-term data are available only at two(2) stations before 1980 including Cagayan de Oro and Malaybalay only. There are many data missing during 20 years before 1980. Therefore, analysis period was determined for 33 years from 1980 to 2012.

The rainfall stations selected through (1) and (2) described above are summarized in Table 3.2.1.

Table 3.2.1 Selected Stations

No.	Station	Location		Elevation (El., m)	Available Data (Years)	Source
		Longitude	Latitude			
1	Baungon	N 8° 18' 46"	E 124° 41' 00"	404	’05-’11 (7)	MAO(*2)
2	Cagayan de Oro	N 8° 29' 00"	E 124° 38' 00"	6	’50-’09 (60)	PAGASA
3	CMU	N 7° 56' 00"	E 125° 04' 00"	412	’80-’12 (33)	PAGASA
4	Kisolon	N 8° 17' 00"	E 124° 56' 00"	675	’80-’06 (27)	PAGASA
5	Libuna	N 8° 22' 50"	E 124° 42' 00"	309	’06-‘12(7)	MAO(*2)
6	Lumbia	N 8° 26' 00"	E 124° 37' 00"	182	’76-‘12(37)	PAGASA
7	Malaybalay	N 8° 09' 07"	E 125° 07' 37"	603	’49-‘12(64)	PAGASA
8	Talakag	N 8° 13' 48"	E 124° 36' 00"	404	’06-’12 (7)	MAO(*2)
9	Damilag(*1)	N 8° 23' 00"	E 124° 47' 00"	591	’67-’84 (18)	PAGASA
10	PON(F42),	N 8° 16' 48"	E 125° 46' 51"	706	’92-‘12(21)	Del Monte
11	F46	N 8° 14' 04"	E 125° 47' 44"	736	’’04-‘12(9)	Del Monte

Notes (*1) : Damilag station has daily record for four years only during 1972 to 1975 which period is out of the analysis period. Hourly rainfall record is available during TS. Sendong which is used for determination of storm hyetgraph during TS. Sendong.

(*2) : Manicipality Agriculture Office

Source: JICA Survey Team

3.3 Basin Mean Daily Rainfall

The following three(3) methods to obtain the basin mean 1-day rainfall were adopted in consideration of the constraints comprising i) most of available stations are located in or around north and east parts of the CDO River basin and only a few stations locates inside the river basin, ii) available data period of those stations are incoherent and iii) even station where long-term period of data are available, no continuous availability can be expected due to short and/or long period of no observation.

(i) Average of daily rainfall data at the selected stations with data interpolation by applying Thiessen method(one Thiessen pattern throughout 33 years)

(ii) Arithmetic mean of observed data at the stations available

(iii) Average daily rainfall data at the stations available on the day of basin mean 1-day maximum rainfall by applying Thiessen method by the year

(1) Basin Mean Rainfall of the Selected Stations with Data Interpolation

A certain number of fixed rainfall stations are used throughout an analysis period. Selection of the stations were made as follows:

i) According to the locations of stations to be spread out over the area adjacent to the river basin as well as data available period of the stations out of 11 stations(to be

more than 20 years including data missing period) shown in Table 3.2.1 :
CDO, CMU, Lumbia, PON

ii) F46 Station which has a remarkable and characteristic daily rainfall data of 475 mm/day during TS. Sendong, which will affect on basin mean rainfall

iii) Talakag Station is located in south part of the basin and to be a dominant station when a basin mean rainfall is estimated by Thiessen method although rather low amount of rainfall at 48.8 mm/day during TS. Sendong.

Non-record period (data missing period) of each selected station is filled up by interpolation by using other station out of 11 stations listed in Table 3.2.1 Interpolation for the respective station is made by multiplying correlation parameter as shown in Table 3.3.2 with a station which has the highest correlation as long as such station has data in the designated period, otherwise, a station with the second highest correlation. In case that rather many stations out of the aforementioned six(6) stations needed to be interpolated and when it was obliged to use the available data with not sufficiently high correlations, the estimated basin mean rainfall may not reflect local precipitation condition in the period.

So as to study an effect of F46 and Talakag respectively, the basin mean rainfall are estimated by applying Thiessen method with different Thiessen polygon of respective station combination as follows:

Table 3.3.1 Thiessen Pattern and Coefficient(1)

Case	Pattern	Stations Incorporated	Thiessen Polygon
Thiessen- 1	without Talakag	CDO, CMU, PON, Lumbia, F46	Figure 3.3.1 (Thiessen-1)
Thiessen- 2	without Talakag and F46	CDO, CMU, PON, Lumbia	Figure 3.3.1 (Thiessen-2)
Thiessen- 3	with Talakag and F46	CDO, CMU, PON, Lumbia, F46, Talakag	Figure 3.3.1 (Thiessen-3)

Case	CDO	CMU	Lumbia	Talakag	PON	F46	Total
Thiessen- 1	0.036	0.002	0.159	-	0.224	0.579	1.000
Thiessen- 2	0.036	0.022	0.159	-	0.783	-	1.000
Thiessen- 3	0.037	0.002	0.059	0.416	0.103	0.383	1.000

Source: JICA Survey Team

Table 3.3.2 Estimated Correlation Ratio and Formula of Rainfall Station

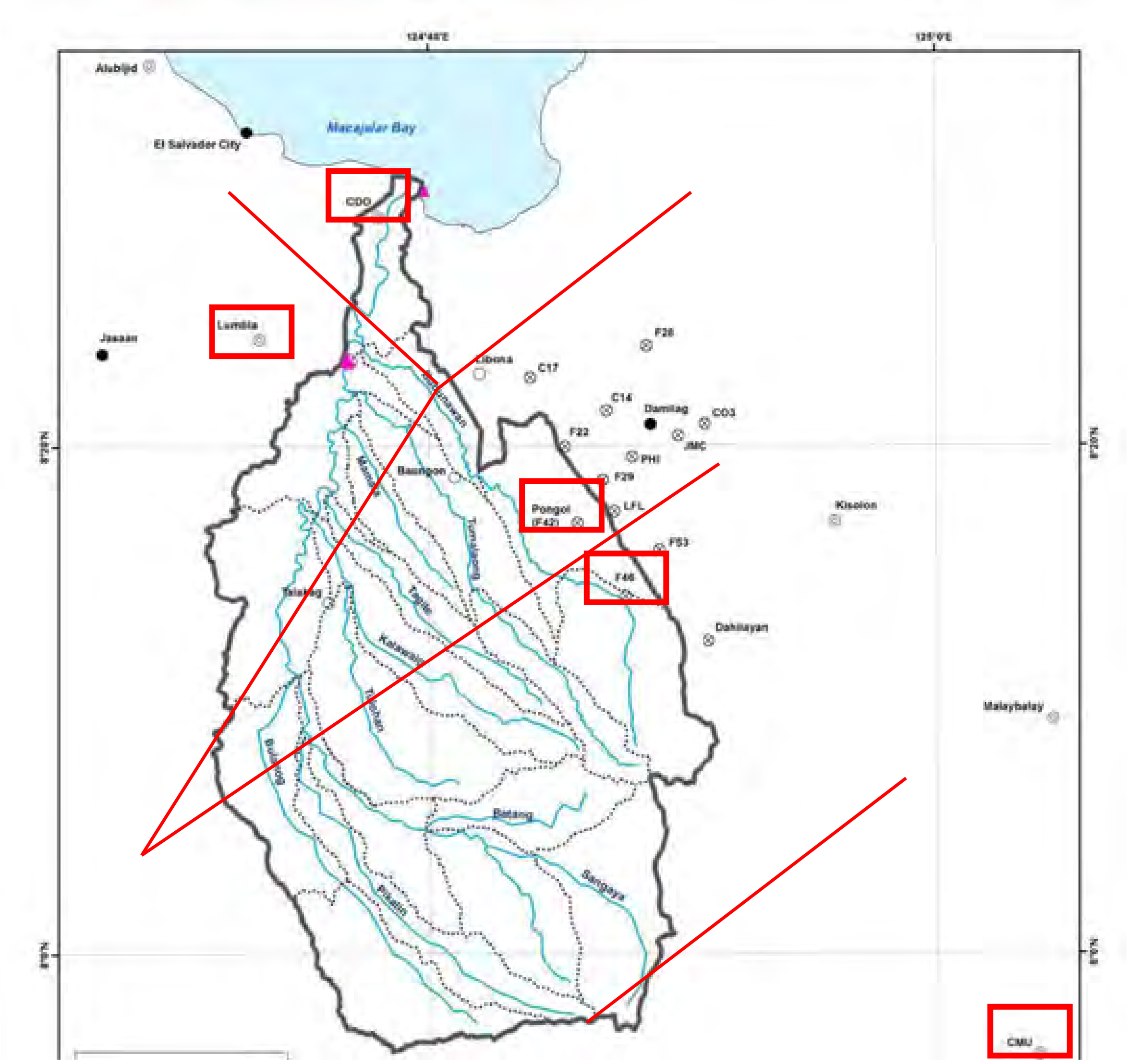
Correlation Coefficient (=R)

No.	Station Name	No.																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Station Name																	
		Dangcagan	Alubjid	Baungon	CDO	Claveria	CMU	Dalwangan	Kisolon	Libuna	Lumbia	Malaybalay	Talakag	Damilag	Kapatagan	Butuan	Pon (F42)	LFL	F46
1	Dangcagan		0.332	0.191	0.352	0.363	0.529	0.408	0.508	0.407	0.410	0.438	0.696	0.000	0.000	-0.075	0.541	0.500	0.633
2	Alubjid	0.332		0.414	0.652	0.679	0.371	0.506	0.443	0.817	0.652	0.515	0.623	0.000	0.000	0.465	0.594	0.615	0.542
3	Baungon	0.191	0.414		0.492	0.718	0.644	0.534	0.165	0.818	0.651	0.451	0.707	0.000	0.000	0.263	0.741	0.717	0.751
4	Cagayan De Oro	0.352	0.652	0.492		0.703	0.605	0.659	0.577	0.749	0.856	0.609	0.776	0.728	0.000	0.300	0.631	0.674	0.630
5	Claveria	0.363	0.679	0.718	0.703		0.568	0.452	0.759	0.626	0.696	0.646	0.555	0.000	0.000	0.208	0.739	0.725	0.648
6	CMU	0.529	0.371	0.644	0.605	0.568		0.691	0.460	0.601	0.586	0.681	0.590	0.000	0.000	-0.011	0.632	0.650	0.628
7	Dalwangan	0.408	0.506	0.534	0.659	0.452	0.691		0.617	0.359	0.646	0.815	0.533	0.000	0.000	-0.191	0.519	0.570	0.642
8	Kisolon	0.508	0.443	0.165	0.577	0.759	0.460	0.617		0.952	0.600	0.564	0.684	0.000	0.000	0.148	0.702	0.760	0.763
9	Libuna	0.407	0.817	0.818	0.749	0.626	0.601	0.359	0.952		0.719	0.502	0.614	0.000	0.000	0.201	0.731	0.721	0.660
10	Lumbia	0.410	0.652	0.651	0.856	0.696	0.586	0.646	0.600	0.719		0.704	0.626	0.000	0.000	0.261	0.729	0.761	0.687
11	Malaybalay	0.438	0.515	0.451	0.609	0.646	0.681	0.815	0.564	0.502	0.704		0.537	0.601	0.000	0.094	0.660	0.654	0.642
12	Talakag	0.696	0.623	0.707	0.776	0.555	0.590	0.533	0.684	0.614	0.626	0.537		0.000	0.000	0.028	0.737	0.730	0.790
13	Damilag	0.000	0.000	0.000	0.728	0.000	0.000	0.000	0.000	0.000	0.000	0.601	0.000		0.000	0.000	0.000	0.000	0.000
14	Kapatagan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000
15	Butuan	-0.075	0.465	0.263	0.300	0.208	-0.011	-0.191	0.148	0.201	0.261	0.094	0.028	0.000	0.000		0.127	0.141	0.078
16	Pongol (F42)	0.541	0.594	0.741	0.631	0.739	0.632	0.519	0.702	0.731	0.729	0.660	0.737	0.000	0.000	0.127		0.892	0.885
17	LFL	0.500	0.615	0.717	0.674	0.725	0.650	0.570	0.760	0.721	0.761	0.654	0.730	0.000	0.000	0.141	0.892		0.858
18	F46	0.633	0.542	0.751	0.630	0.648	0.628	0.642	0.763	0.660	0.687	0.642	0.790	0.000	0.000	0.078	0.885	0.858	

Correlation Coefficient (=P, A station = B station x P)

No.	Station Name	No.																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Station Name																	
		Dangcagan	Alubjid	Baungon	CDO	Claveria	CMU	Dalwangan	Kisolon	Libuna	Lumbia	Malaybalay	Talakag	Damilag	Kapatagan	Butuan	Pon (F42)	LFL	F46
1	Dangcagan		0.593	0.958	0.786	1.174	0.632	0.785	1.040	1.009	0.723	1.072	1.158	0.000	0.000	0.850	1.378	1.243	1.416
2	Alubjid	1.686		3.794	1.417	2.945	2.309	2.727	2.053	3.276	1.521	2.268	3.228	0.000	0.000	1.859	2.753	2.484	4.172
3	Baungon	1.044	0.264		0.543	1.262	0.839	0.956	0.763	1.344	0.606	0.858	1.191	0.000	0.000	0.645	1.153	1.039	1.416
4	Cagayan De Oro	1.273	0.706	1.841		1.868	1.521	1.621	1.400	2.029	1.066	1.706	1.864	1.274	0.000	1.294	2.065	1.843	2.427
5	Claveria	0.852	0.340	0.792	0.535		0.670	0.903	0.608	0.974	0.540	0.770	1.157	0.000	0.000	0.600	1.001	0.927	1.347
6	CMU	1.582	0.433	1.192	0.657	1.492		1.281	0.960	1.432	0.723	1.153	1.744	0.000	0.000	0.855	1.525	1.375	2.044
7	Dalwangan	1.274	0.367	1.046	0.617	1.107	0.781		0.804	1.031	0.583	0.916	1.319	0.000	0.000	0.729	1.181	1.037	1.548
8	Kisolon	0.962	0.487	1.310	0.714	1.644	1.042	1.244		1.383	0.767	1.157	1.340	0.000	0.000	0.916	1.502	1.347	1.709
9	Libuna	0.991	0.305	0.744	0.493	1.027	0.698	0.970	0.723		0.572	0.833	1.256	0.000	0.000	0.558	1.055	0.957	1.455
10	Lumbia	1.384	0.657	1.649	0.938	1.853	1.383	1.716	1.304	1.747		1.516	2.131	0.000	0.000	1.185	1.898	1.707	2.560
11	Malaybalay	0.933	0.441	1.165	0.586	1.299	0.867	1.092	0.864	1.201	0.660		1.414	0.826	0.000	0.801	1.290	1.155	1.672
12	Talakag	0.863	0.310	0.840	0.537	0.864	0.573	0.758	0.746	0.796	0.469	0.707		0.000	0.000	0.498	0.903	0.798	1.204
13	Damilag	0.000	0.000	0.000	0.785	0.000	0.000	0.000	0.000	0.000	0.000	1.211	0.000		0.000	0.000	0.000	0.000	0.000
14	Kapatagan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000
15	Butuan	1.177	0.538	1.551	0.773	1.667	1.170	1.372	1.091	1.791	0.844	1.248	2.007	0.000	0.000		1.602	1.430	2.155
16	Pongol (F42)	0.726	0.363	0.867	0.484	0.999	0.656	0.847	0.666	0.948	0.527	0.775	1.108	0.000	0.000	0.624		0.898	1.351
17	LFL	0.804	0.403	0.962	0.543	1.079	0.727	0.965	0.742	1.045	0.586	0.866	1.253	0.000	0.000	0.699	1.113		1.474
18	F46	0.706	0.240	0.706	0.412	0.742	0.489	0.646	0.585	0.688	0.391	0.598	0.830	0.000	0.000	0.464	0.740	0.678	

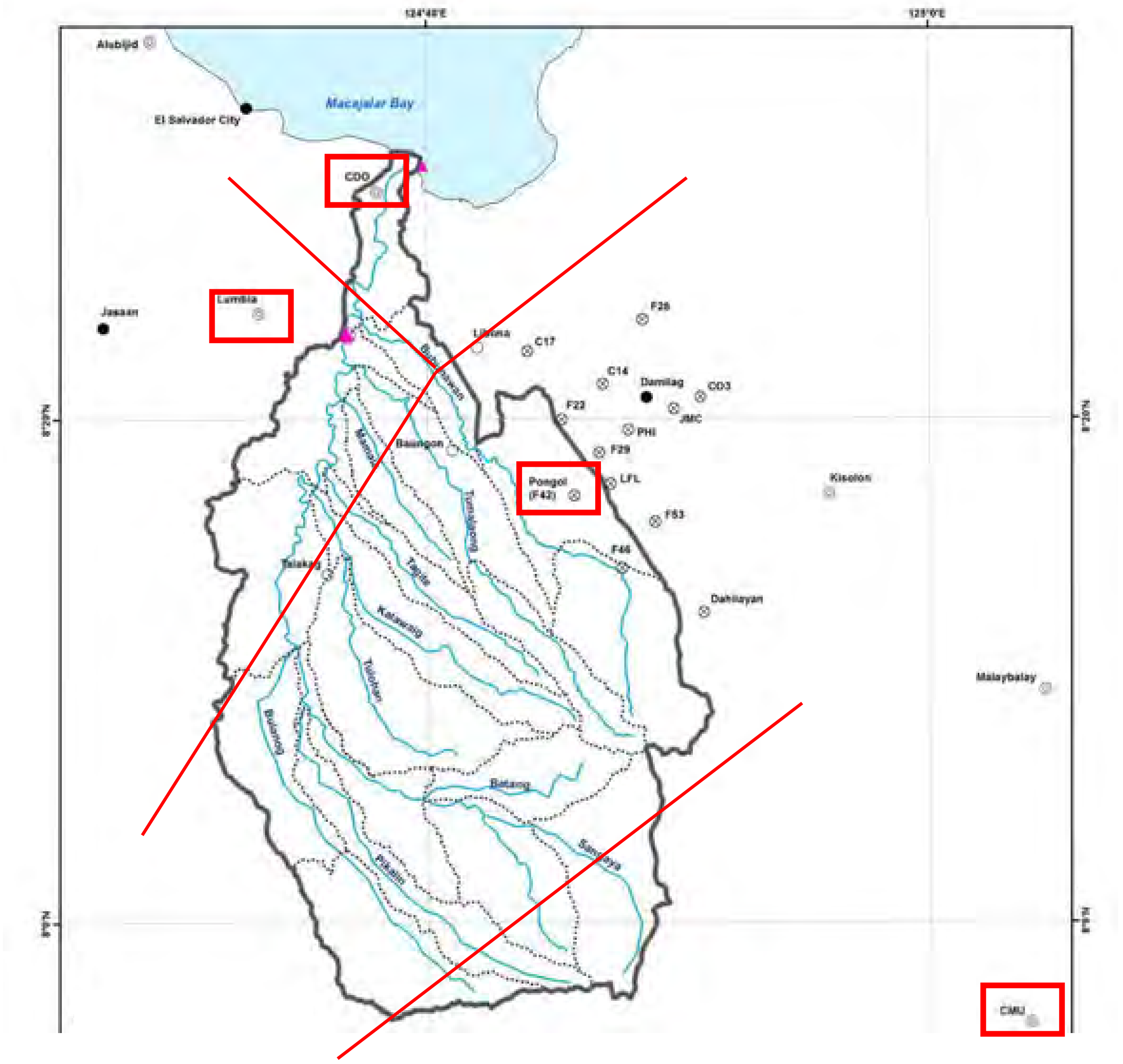
Source: JICA Survey Team



Case		CDO	CMU	Lumbia	Talakag	PON (F42)	F46	Total
Thiessen-1	Area (km^2)	49	3	217	-	306	790	1,364
	Coeff.	0.036	0.002	0.159	-	0.224	0.579	1.000
Thiessen-2	Area (km^2)	49	30	217	-	1068	-	1,364
	Coeff.	0.036	0.022	0.159	-	0.783	-	1.000
Thiessen-3	Area (km^2)	50	3	80	567	140	522	1,364
	Coeff.	0.037	0.002	0.059	0.416	0.103	0.383	1.000

Source: JICA Survey Team

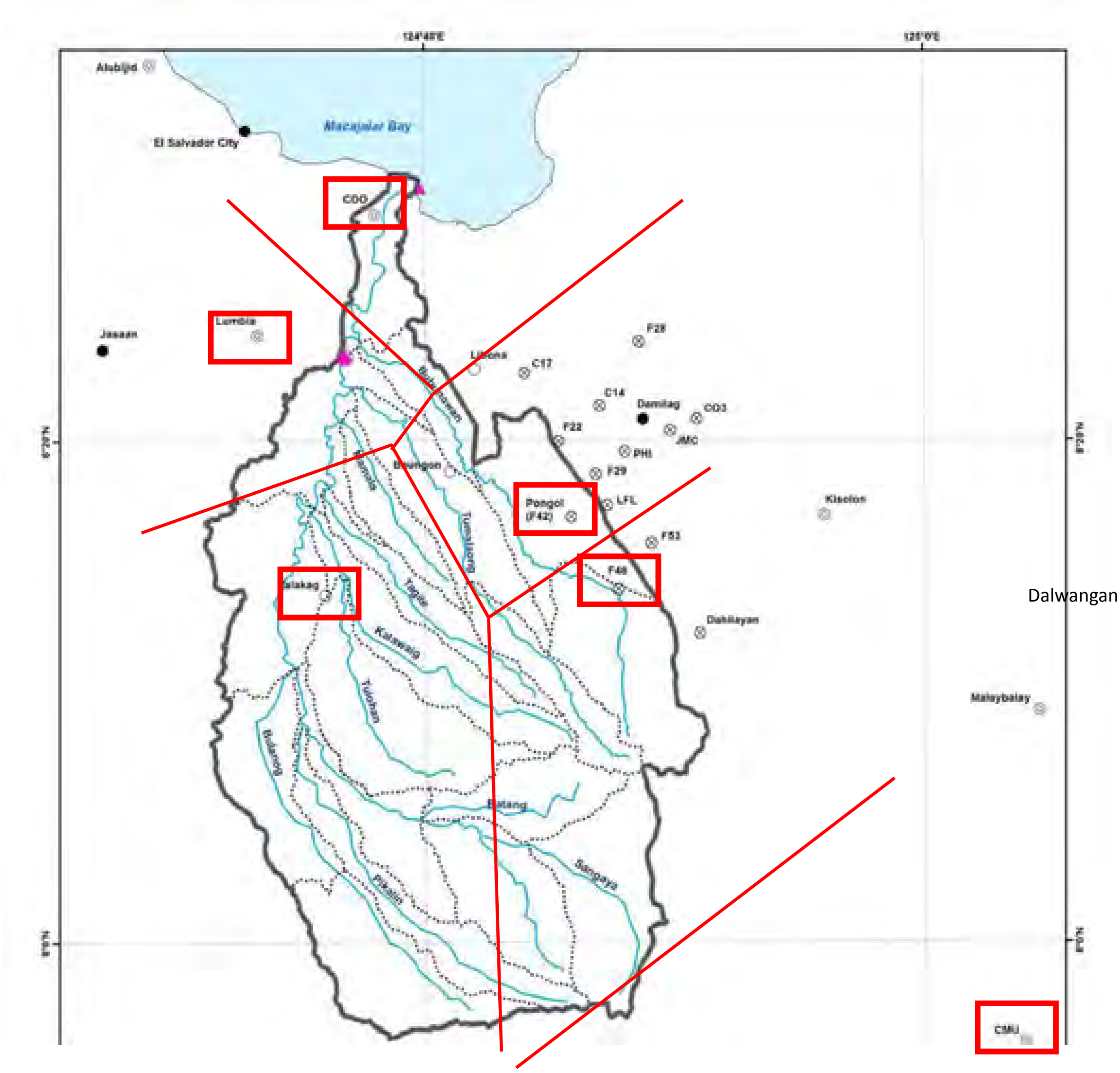
Figure 3.3.1 Thiessen Polygon (Data Interpolation Thiessen- 1)



Case		CDO	CMU	Lumbia	Talakag	PON (F42)	F46	Total
Thiessen-1	Area (km^2)	49	3	217	-	306	790	1,364
	Coeff.	0.036	0.002	0.159	-	0.224	0.579	1.000
Thiessen-2	Area (km^2)	49	30	217	-	1068	-	1,364
	Coeff.	0.036	0.022	0.159	-	0.783	-	1.000
Thiessen-3	Area (km^2)	50	3	80	567	140	522	1,364
	Coeff.	0.037	0.002	0.059	0.416	0.103	0.383	1.000

Source: JICA Survey Team

Figure 3.3.1 Thiessen Polygon (Data Interpolation Thiessen- 2)



Case		CDO	CMU	Lumbia	Talakag	PON (F42)	F46	Total
Thiessen-1	Area (km^2)	49	3	217	-	306	790	1,364
	Coeff.	0.036	0.002	0.159	-	0.224	0.579	1.000
Thiessen-2	Area (km^2)	49	30	217	-	1068	-	1,364
	Coeff.	0.036	0.022	0.159	-	0.783	-	1.000
Thiessen-3	Area (km^2)	50	3	80	567	140	522	1,364
	Coeff.	0.037	0.002	0.059	0.416	0.103	0.383	1.000

Source: JICA Survey Team

Figure 3.3.1 Thiessen Polygon (Data Interpolation Thiessen- 3)

The annual maximum basin mean 1-day rainfall estimated for the respective Thiessen cases are shown in Table 3.3.3.

Table 3.3.3 Annual Maximum Basin Mean 1-day Rainfall (Data Interpolation, Fixed Thiessen)

Thiessen-1		Thiessen-2		Thiessen-3	
Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall(mm)	Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall(mm)	Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall(mm)
20/10/1980	238.5	20/10/1980	191.0	20/10/1980	242.2
17/07/1981	134.5	17/07/1981	108.0	17/07/1981	136.6
03/10/1982	179.6	03/10/1982	143.4	19/03/1982	182.3
25/06/1983	170.7	25/06/1983	136.7	04/08/1983	173.3
01/09/1984	170.5	01/09/1984	137.2	01/09/1984	173.2
04/01/1985	207.0	04/01/1985	166.4	04/01/1985	210.2
03/07/1986	160.4	03/07/1986	128.2	26/01/1986	162.8
24/08/1987	185.8	24/08/1987	149.0	24/08/1987	188.6
07/07/1988	179.4	07/07/1988	143.5	07/07/1988	182.2
25/06/1989	160.7	25/06/1989	128.9	25/06/1989	163.1
12/11/1990	246.5	12/11/1990	197.6	12/11/1990	250.3
13/03/1991	123.7	13/03/1991	98.6	13/03/1991	125.6
28/07/1992	143.6	28/07/1992	115.1	28/07/1992	145.8
26/12/1993	95.7	26/12/1993	75.6	26/12/1993	100.3
13/06/1994	93.3	13/06/1994	73.6	13/06/1994	98.2
27/12/1995	133.3	27/12/1995	104.8	27/12/1995	142.0
03/06/1996	124.7	03/06/1996	98.3	03/06/1996	132.8
13/04/1997	122.7	13/04/1997	96.1	13/04/1997	131.8
09/11/1998	131.8	09/11/1998	104.3	09/11/1998	137.2
05/02/1999	127.8	05/02/1999	105.9	22/12/1999	127.2
05/06/2000	136.7	05/06/2000	109.2	05/06/2000	140.6
21/11/2001	114.7	21/11/2001	93.5	21/11/2001	113.7
19/06/2002	117.7	19/06/2002	95.0	19/06/2002	118.4
06/07/2003	118.1	06/07/2003	95.3	06/07/2003	122.7
01/06/2004	107.0	01/06/2004	83.8	01/06/2004	114.8
05/07/2005	75.4	19/10/2005	64.4	13/06/2005	82.2
13/06/2006	61.9	25/05/2006	70.4	26/06/2006	60.6
26/06/2007	85.3	26/06/2007	85.2	25/10/2007	71.4
20/08/2008	132.0	28/04/2008	83.8	26/04/2008	153.0
02/01/2009	149.6	02/01/2009	152.0	24/11/2009	143.3
19/09/2010	109.5	19/09/2010	209.8	23/07/2010	117.5
16/12/2011	321.6	16/12/2011	76.2	16/12/2011	224.6
8/24/2012	94.1	8/31/2012	51.5	12/4/2012	107.2

Source: the Survey Team

Out of three (3) ways, cases of Thiessen-2 and -3 seems not realistic according to the following reasons:

i) As seen in Table 3.3.3, computed annual maximum basin mean 1-day rainfall in 2011 of Thiessen-2 is too small although the storm during TS.Sendong in 2011 is said to be the biggest storm in the past more than 50 years.

ii) Computed annual maximum basin mean 1-day rainfall in 2012 of Thiessen-1 is on August 24 even though the big typhoon, TY Pablo attacked on December 4.

iii) In case of Thiessen-3, 1-day maximum rainfall amounts in several years are higher than that in 2011 corresponding to the storm during TS. Sendong, and as shown in Table 3.3.4 (Thiessen-3), the frequency analysis result shows that the occurrence frequency of the 1-day rainfall in TS. Sendong is assessed at 20-year only.

Table 3.3.4 Results of Frequency Analysis of Basin Mean Rainfall (Thiessen-3)

	1-day Basin Mean Rainfall(mm)									
	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTak	LN3Q	LN3PM
X-COR(99%)	0.96	0.989	0.977	0.992	0.992	0.992	0.992	0.992	0.992	0.992
P-COR(99%)	0.91	0.996	0.995	0.995	0.993	0.995	0.995	0.995	0.994	0.995
SLSC(99%)	0.056	0.029	0.042	0.027	0.025	0.024	0.024	0.024	0.025	0.024
Log Likelihood	-162.4	-170.6	-171.5	-170.4	-170.4	-170.3	-170.4	-170.4	-170.4	-170.4
pAIC	328.8	345.2	347	346.8	346.8	346.7	346.8	346.8	346.8	346.8
X-COR(50%)	0.967	0.975	0.962	0.979	0.986	0.992	0.981	0.982	0.982	0.982
P-COR(50%)	0.994	0.994	0.995	0.994	0.995	0.995	0.995	0.995	0.994	0.995
SLSC(50%)	0.076	0.052	0.076	0.049	0.056	0.047	0.046	0.049	0.052	0.049

Probability	Return T	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTak	LN3Q	LN3PM
	2-yr	123.8	131.6	130.0	132.9	135.8	134.4	134	134.4	134.7	134.5
	5-yr	170.0	172.9	177.2	174.1	175.7	174.8	174.2	174.1	173.7	174.2
	10-yr	205.0	200.2	212.1	200.1	198.3	198.9	199.0	198.0	197.1	198.0
	25-yr	251.2	234.7	260.2	231.7	223.4	227.1	228.5	226.4	224.6	226.2
	50-yr	286.2	260.3	298.8	254.2	240.0	246.6	249.6	246.3	243.8	246.1
	80-yr	309.9	277.5	326.1	268.9	250.4	259.3	263.5	259.4	256.4	259.0
	100-yr	321.1	285.7	339.5	275.8	255.1	265.1	270.0	265.5	262.3	265.1
	Sendong	224.6 mm									
		16yr	19yr	13yr	20yr	26yr	23yr	22yr	24yr	25yr	24yr

Jack Knife Estimate	Return T	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTak	LN3Q	LN3PM
	2-yr	123.8	131.6	129.9	132.8	134.5	134.2	135.1	134.8	144.3	135.1
	5-yr	170.0	172.9	179.1	174.4	175.6	175.3	174.9	175.1	177.1	175.3
	10-yr	205.0	200.2	215.5	200.6	199.9	199.7	198.2	198.9	189.5	198.9
	25-yr	251.2	234.7	265.7	231.9	227.6	227.8	225.0	226.5	197.9	226.1
	50-yr	286.2	260.3	305.9	253.8	246.3	246.9	243.5	245.6	200.0	244.9
	80-yr	309.9	277.5	334.5	267.7	258.2	259.0	255.3	258.0	199.7	257.0
	100-yr	321.1	285.7	348.4	274.2	263.6	264.6	260.8	263.7	199.2	262.5
	Sendong	224.6 mm									
		16yr	19yr	12 yr	20yr	23yr	23yr	25yr	24yr	NA	24yr

Jack Knife Error	Return T	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTak	LN3Q	LN3PM
	2-yr	7.0	7.3	7.3	8.2	8.6	8.1	7.6	8.6	9.3	8.6
	5-yr	10.3	10.6	11.5	11.3	11.3	10.8	10.5	11.1	10.8	11.1
	10-yr	14.0	13.5	16.3	13.4	12.5	13.2	13.2	12.6	11.9	12.6
	25-yr	23.9	20.7	30.5	22.7	16.2	23.2	20.8	17.2	18.4	17.2
	50-yr	26.9	22.8	35.3	27.1	18.0	27.4	23.5	19.1	21.4	19.0
	80-yr	28.4	23.9	37.7	29.5	19.0	29.6	24.8	20.1	22.9	20.0
	100-yr	7.0	7.3	7.3	8.2	8.6	8.1	7.6	8.6	9.3	8.6

Source: JICA Survey Team

(2) Arithmetic Mean of the Records at Stations Available

The annual maximum basin mean 1-day rainfall every year were estimated by calculating an arithmetic mean of the records at all the stations that the daily rainfall record is available. The rainfall stations used for calculation are 11 stations as listed in Table 3.2.1.

As seen in Table 3.3.5, it seems not reasonable that the highest amount occurred in 2003 and it is about 1.5 times of that occurred on December 16, 2011 during TS. Sendong. Furthermore, the second highest amount occurred in 2004. Therefore, it was judged that the annual maximum basin mean rainfall estimated by the arithmetic average of the stations was not applicable.

Table 3.3.5 Annual Maximum Basin Mean 1-day Rainfall (Arithmetic Mean)

Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall (mm)	Nos. of Stations used for Calculation
20/10/1980	49.9	7
24/01/1981	55.9	6
19/03/1982	72.1	5
04/09/1983	41.5	6
01/09/1984	50.0	7
17/12/1985	68.1	6
21/12/1986	38.8	7
13/12/1987	43.0	7
23/10/1988	44.0	7
17/07/1989	44.1	7
12/11/1990	76.8	7
24/04/1991	75.0	6
01/08/1992	48.1	6
25/12/1993	63.6	7
31/08/1994	59.3	7
10/09/1995	61.4	7

Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall (mm)	Nos. of Stations used for Calculation
11/06/1996	70.3	7
12/07/1997	47.7	7
21/08/1998	50.0	7
05/02/1999	96.0	7
30/11/2000	60.2	7
21/11/2001	56.8	7
04/09/2002	115.7	8
15/10/2003	189.0	8
11/02/2004	125.3	7
17/07/2005	87.2	9
25/05/2006	48.2	11
26/06/2007	54.8	10
26/04/2008	65.5	9
24/11/2009	108.8	9
06/07/2010	65.3	8
16/12/2011	121.2	8
2012/12/04	87.4	8

Source: JICA Survey Team

(3) Mean of Records at Stations by Applying Thiessen Pattern by the Year

The annual maximum basin mean rainfall was estimated through the way that Thiessen polygon is prepared every year by using rainfall stations available, among 11 stations listed in Table 3.2.1, on the day when annual maximum occurred. Consequently, this method needed 12 Thiessen patterns to meet required combination in 33 years. Those Thiessen pattern are shown in Appendix P in DATA BOOK and Thiessen coefficient are respectively shown in Table 3.3.6.

The annual maximum basin mean rainfall is estimated according to the said 12 Thiessen patterns applicable for the respective year as shown in Table 3.3.7.

Table 3.3.6 Thiessen Coefficient

T-pattern		Baungon	CDO	CMU	Kisolon	Libuna	Lumbia	Malaybalay	Talakag	Damilag	PON (F42)	F46	Total
t-1	Area (km^2)	-	53	150	-	-	441	20	-	700	-	-	1,364
	Coeff.	-	0.039	0.110	-	-	0.323	0.015	-	0.513	-	-	1.000
t-2	Area (km^2)	-	83	208	-	-	901	171	-	-	-	-	1,364
	Coeff.	-	0.061	0.153	-	-	0.661	0.126	-	-	-	-	1.000
t-3	Area (km^2)	-	81	-	-	-	934	350	-	-	-	-	1,364
	Coeff.	-	0.059	-	-	-	0.684	0.256	-	-	-	-	1.000
t-4	Area (km^2)	-	60	119	498	-	687	-	-	-	-	-	1,364
	Coeff.	-	0.044	0.088	0.365	-	0.503	-	-	-	-	-	1.000
t-5	Area (km^2)	-	64	-	601	-	681	18	-	-	-	-	1,364
	Coeff.	-	0.047	-	0.441	-	0.499	0.013	-	-	-	-	1.000
t-6	Area (km^2)	-	50	-	1	-	214	-	-	-	1,099	-	1,364
	Coeff.	-	0.037	-	0.001	-	0.157	-	-	-	0.806	-	1.000
t-7	Area (km^2)	-	49	-	-	-	213	-	-	-	1,102	-	1,364
	Coeff.	-	0.036	-	-	-	0.156	-	-	-	0.808	-	1.000
t-8	Area (km^2)	479	44	-	-	-	76	-	-	-	71	695	1,364
	Coeff.	0.351	0.032	-	-	-	0.055	-	-	-	0.052	0.509	1.000
t-9	Area (km^2)	132	36	2	-	41	45	-	618	-	73	418	1,364
	Coeff.	0.097	0.026	0.001	-	0.030	0.033	-	0.453	-	0.054	0.307	1.000
t-10	Area (km^2)	132	35	-	-	41	40	-	611	-	76	428	1,364
	Coeff.	0.097	0.026	-	-	0.030	0.029	-	0.448	-	0.056	0.314	1.000
t-11	Area (km^2)	131	-	3	-	55	70	-	594	-	74	438	1,364
	Coeff.	0.096	-	0.002	-	0.040	0.051	-	0.435	-	0.054	0.321	1.000
t-12	Area (km^2)	-	-	3	-	99	73	-	658	-	101	430	1,364
	Coeff.	-	-	0.002	-	0.073	0.054	-	0.482	-	0.074	0.315	1.000

Source: JICA Survey Team

Table 3.3.7 Annual Maximum Basin Mean 1-day Rainfall by Applying Thiessen Pattern by Year

Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall (mm)	Thiessen Pattern	Nos. of Stations used for Calculation	Occurrence Date of Annual Max.	Annual Max. 1-day Rainfall (mm)	Used T-sen Pattern	Nos. of Stations used for Calculation
20/10/1980	51.7	t-1	5	03/06/1996	100.2	t-6	4
24/01/1981	53.3	t-2	4	13/04/1997	98.5	t-6	4
19/03/1982	90.9	t-3	3	09/11/1998	106.9	t-6	4
25/06/1983	60.3	t-3	3	22/12/1999	104.6	t-7	3
01/09/1984	52.5	t-4	4	05/06/2000	111.5	t-6	4
04/01/1985	70.2	t-4	4	21/11/2001	95.2	t-6	4
19/09/1986	46.1	t-5	4	19/06/2002	96.7	t-6	4
24/08/1987	51.0	t-4	4	06/07/2003	95.9	t-6	4
23/10/1988	65.4	t-4	4	01/06/2004	85.7	t-6	4
17/07/1989	70.5	t-4	4	13/06/2005	63.4	t-8	6
12/11/1990	121.4	t-4	4	01/06/2006	59.6	t-9	8
24/04/1991	108.4	t-5	4	26/06/2007	68.3	t-9	8
28/07/1992	60.6	t-5	4	20/08/2008	109.1	t-8	6
26/12/1993	77.4	t-6	4	24/11/2009	145.8	t-11	7
13/06/1994	75.5	t-6	4	06/07/2010	124.2	t-12	6
27/12/1995	107.5	t-6	4	16/12/2011	187.2	t-12	6
				04/12/2012	111.7	t-12	6

Source: JICA Survey Team

According to the series of annual maximum basin mean 1-day rainfall estimated by this method, it shows no contradiction to the actual rainfall record that daily amount in 2011 occurred on the TS. Sendong day is the highest in the past 33 years. Furthermore, the years with rather higher amounts are found after 1995 which considerably correspond to a tendency as seen in Table 2.1.3.

(4) Evaluation of Relevant Estimate of the Maximum Basin Mean Daily Rainfall

Out of three(3) methods to estimate a maximum basin mean daily rainfall, the method of applying Thiessen pattern by the year as described in (3) mentioned above is the most appropriate method.

So as to evaluate the said method, the following evaluation procedure was applied:

i) Water level record(3-time a day and extreme records) at the Cabula Bridge is available for period of 1991 to 2011.

ii) Ranking comparison of the annual highest water level(at the Cabula Bridge) and basin average annual maximum rainfall(Thiessen pattern by the year) in terms of respective occurrence year

iii) Annual highest water level at the Cabula Bridge and the basin average annual maximum rainfall(Thiessen pattern by the year) are as follows:

Table 3.3.8 Annual Ranking of Water Level and Basin Average Annual Maximum Rainfall

Year	Annual Highest Waterstage		Basin Mean Rainfall	
	WL	Rank	Rainfall	Rank
1991	2.80	18	108.4	7
1992	2.70	21	60.6	21
1993	3.04	16	77.4	17
1994	3.50	7	75.5	18
1995	3.03	17	107.5	8
1996	2.80	18	100.2	11
1997	2.51	22	98.5	12
1998	2.80	18	106.9	9
1999	3.30	10	104.6	10
2000	4.80	4	111.5	5
2001	3.30	10	95.2	15
2002	3.45	8	96.7	13
2003	4.20	5	95.9	14
2004	3.30	10	85.7	16
2005	3.30	10	63.4	20
2006	3.39	9	59.6	22
2007	3.15	15	68.3	19
2008	3.56	6	109.1	6
2009	4.90	3	145.8	2
2010	3.20	14	124.2	3
2011	9.80	1	187.2	1
2012	7.20	2	111.7	4

Rank	WL	Rainfall
1	2011	2011
2	2012	2009
3	2009	2010
4	2000	2012
5	2003	2000
6	2008	2008
7	1994	1991
8	2002	1995
9	2006	1998
10	1999	1999
11	2001	1996
12	2004	1997
13	2005	2002
14	2010	2003
15	2007	2001
16	1993	2004
17	1995	1993
18	1991	1994
19	1996	2007
20	1998	2005
21	1992	1992
22	1997	2006

Source: JICA Survey Team

As seen in the table above showing water level and rainfall in descending order(table right side), the order of water level and annual maximum rainfall shows good conformity for the 1^{st} to 6^{th} highest.

However in 2003 case in which the annual highest water level ranks as the 5^{th} highest, the basin mean rainfall locates at 14^{th} from the top. This inconsistency in terms of the order of water level and annual maximum rainfall is clarified as follows:

(a) In 2003 case, the Thiessen pattern as shown in Figure C4-2 (t-6) in Appendix C-4 by which PON station is a predominant station(80% of the basin) to estimate the basin mean rainfall, it is definite that:

  i) High basin mean rainfall would be estimated when higher rainfall is recorded at PON station even if the water level at the Cabula Bridge does not rise remarkably.

  ii) High water level record might be obtained even if not high basin mean rainfall estimated, when high rainfall is observed not at PON but Lumbia and/or Cagayan de Oro stations.

(b) In October 2003 during 13^{th} to 16^{th}, the highest water level was recorded at El. 4.20m at 23:00 of October 14. Although estimated basin mean rainfall on October 14 is about 40 mm which is less than half of the maximum basin mean rainfall estimated on July 6. Through the assessment of rainfall pattern and water level moves, it is observed that the water level rise was caused by the local and severe rainfall which were not reflected to the rainfall records of the stations included in the Thiessen pattern used for 2003.

As stated above, Thiessen pattern by year shows good fit for the relatively-high water level event (1st to 6th highest) which correlate highly with rainfall event. Therefore, Thiessen pattern by the year was adopted for next frequency analysis.

3.4 Probable Rainfall

Using method of Thiessen pattern by the year, annual maximum basin mean 1-day rainfall analysis and partial duration series of basin mean 1-day rainfall analysis were conducted for probability calculation.

(1) Annual Maximum Basin Mean 1-day Rainfall

In the rainfall analysis in the Survey, the rainfall record during TS. Sendong was adopted as the design stormy rainfall since it is the largest recorded storm and flood in the recent 50 years or the highest as far as it has been experienced so far.

Through the analysis described in 3.3, it is obtained that the maximum basin mean 1-day rainfall were obtained as shown in Table 3.4.1. A 1-day rainfall record are adopted in the analysis since it was found during the recent remarkable TS. Sendong storm that 1-day rainfall resulted for 97 – 100% of total rainfall during the storm at the most of the stations in and adjacent the CDO River basin as shown in Table 3.4.2 below:

Table 3.4.1 Annual Maximum Basin Mean 1-day Rainfall

Year	1-day (mm)	Year	1-day (mm)
1980	51.7	1996	100.2
1981	53.3	1997	98.5
1982	90.9	1998	106.9
1983	60.3	1999	104.6
1984	52.5	2000	111.5
1985	70.2	2001	95.2
1986	46.1	2002	96.7
1987	51.0	2003	95.9
1988	65.4	2004	85.7
1989	70.5	2005	63.4
1990	121.4	2006	59.6
1991	108.4	2007	68.3
1992	60.6	2008	106.6
1993	77.4	2009	145.8
1994	75.5	2010	124.2
1995	107.5	2011	187.2
		2012	111.7

Source: JICA Survey Team

Table 3.4.2 Daily Rainfall Record during TS. Sendong

Station	During Storm(mm)			Ratio of 1-day Rainfall(%)
	Dec.16	Dec.17	Dec. 16-17	
Talakag	48.8	0.0	48.8	100.0
Lumbia	180.9	0.5	181.4	99.7
PON	52.0	10.0	62.0	83.9
F46	475.0	14.0	489.0	97.1
Libuna	260.0	2.0	262.0	99.2

Source: JICA Survey Team

Frequency analysis was carried out for annual maximum basin mean 1-day rainfall for 33 years by various distribution as shown in Table 3.4.3. Considering that value of SLSC and visual fitness with the distribution curve as well as Jack-knife method, the SQRT-Exponential type maximum (SqrtEt) distribution was concluded the most appropriate for the statistical analysis of the maximum basin mean rainfall in this Survey. The SLSC value and correlation coefficient as well as JackKnife's estimate and error are shown in Table 3.4.3.

The return period of the rainfall during TS. Sendon was estimated based on the annual maximum rainfall. The SQRT-Exponential type maximum(SqrtEt) distribution shows 53 year return period in annual maximum rainfall case shown in Table 3.4.3. Figure 3.4.1 presents the probable distribution plotting on some probability paper of each distribution.

Table 3.4.3 Results of Frequency Analysis for Annual Maximum Basin Mean 1-day Rainfall

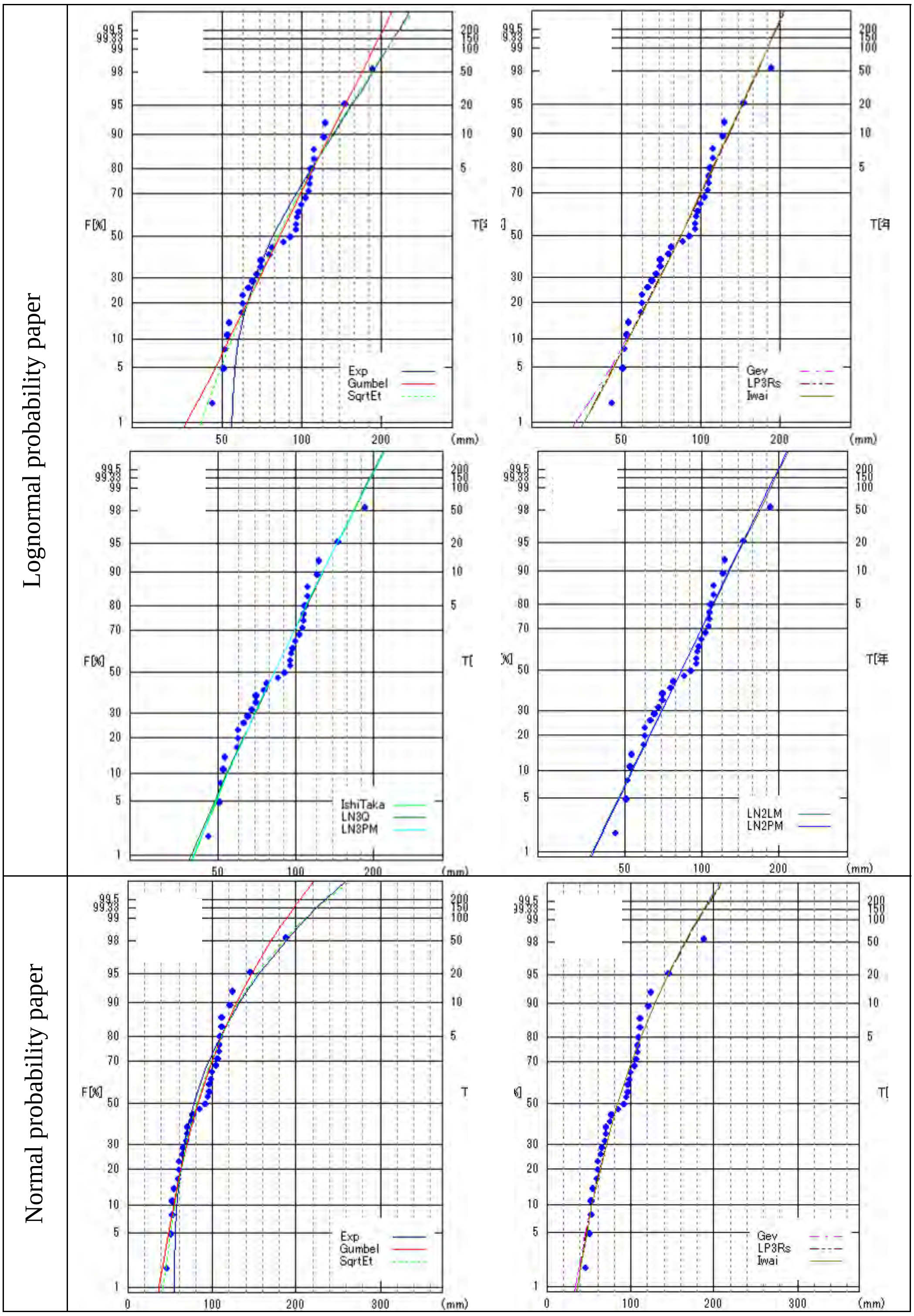
	1-day Basin Mean Rainfall(mm)										
	Exp	Gumbel	SqrtEt	Gev	LP3Rs	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
X-COR(99%)	0.966	0.982	0.98	0.98	0.981	0.981	0.982	0.982	0.982	0.982	0.982
P-COR(99%)	0.965	0.985	0.982	0.986	0.986	0.986	0.984	0.985	0.984	0.986	0.986
SLSC(99%)	0.052	0.038	0.039	0.043	0.039	0.04	0.04	0.039	0.039	0.038	0.039
Log Likelihood	-149.5	-157	-157	-157.2	—	-157	-156.7	-156.7	-156.7	-156.9	-156.8
pAIC	303	318	317.9	320.4	0	320	319.4	319.5	319.4	317.7	317.6
X-COR(50%)	0.965	0.955	0.969	0.947	0.948	0.949	0.957	0.955	0.957	0.953	0.953
P-COR(50%)	0.962	0.971	0.969	0.971	0.971	0.972	0.972	0.972	0.972	0.97	0.972
SLSC(50%)	0.078	0.07	0.073	0.08	0.081	0.08	0.084	0.082	0.084	0.079	0.08

Probability	Return	Exp	Gumbel	SqrtEt	Gev	LP3Rs	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
	2-yr	78.2	83.5	81.7	84.5	84.4	84.5	83.1	83.4	83.2	83.9	83.9
	5-yr	109.5	111.4	110.8	112.4	112.2	111.8	110.6	111	110.7	112.2	111.6
	10-yr	133.2	129.9	132.3	129.8	129.8	129	129	129.1	129	130.6	129.5
	25-yr	164.5	153.3	161.9	150.9	151	150	152.4	152	152.4	153.5	151.9
	50-yr	188.1	170.6	185.6	165.8	166.3	165.2	170	169	169.8	170.5	168.4
	80-yr	204.2	182.3	202.4	175.5	176.5	175.3	181.9	180.6	181.7	181.9	179.4
	100-yr	211.8	187.8	210.6	180.1	181.2	180.1	187.7	186	187.4	187.3	184.7
	Sendong	187.2 mm										
		49yr	98 yr	53 yr	Over100	Over100	Over100	98yr	Over100	9yr	Over100	Over100

Jack Knife Estimate	Return	Exp	Gumbel	SqrtEt	Gev	LP3Rs	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
	2-yr	78.2	83.5	81.5	84.4	163	81.1	82.1	83.4	82.6	83.7	83.7
	5-yr	109.5	111.4	111.1	112.9	218	110.7	111.6	111.7	112.2	111.9	111.5
	10-yr	133.2	129.9	133	130.6	254.7	131.6	131.4	129.7	131.7	130.2	129.5
	25-yr	164.5	153.3	163.1	151.2	301	158.7	156.2	151.2	155.6	152.9	151.8
	50-yr	188.1	170.6	187.3	165	335.1	179.4	174.5	166.2	173	169.7	168.2
	80-yr	204.2	182.3	204.4	173.4	358.1	193.5	186.7	176	184.4	180.9	179.3
	100-yr	211.8	187.8	212.7	177.2	368.9	200.2	192.4	180.5	189.8	186.3	184.5
	Sendong	187.2 mm										
		49yr	98 yr	50 yr	Over100	3yr	67yr	82yr	Over100	90yr	Over100	Over100

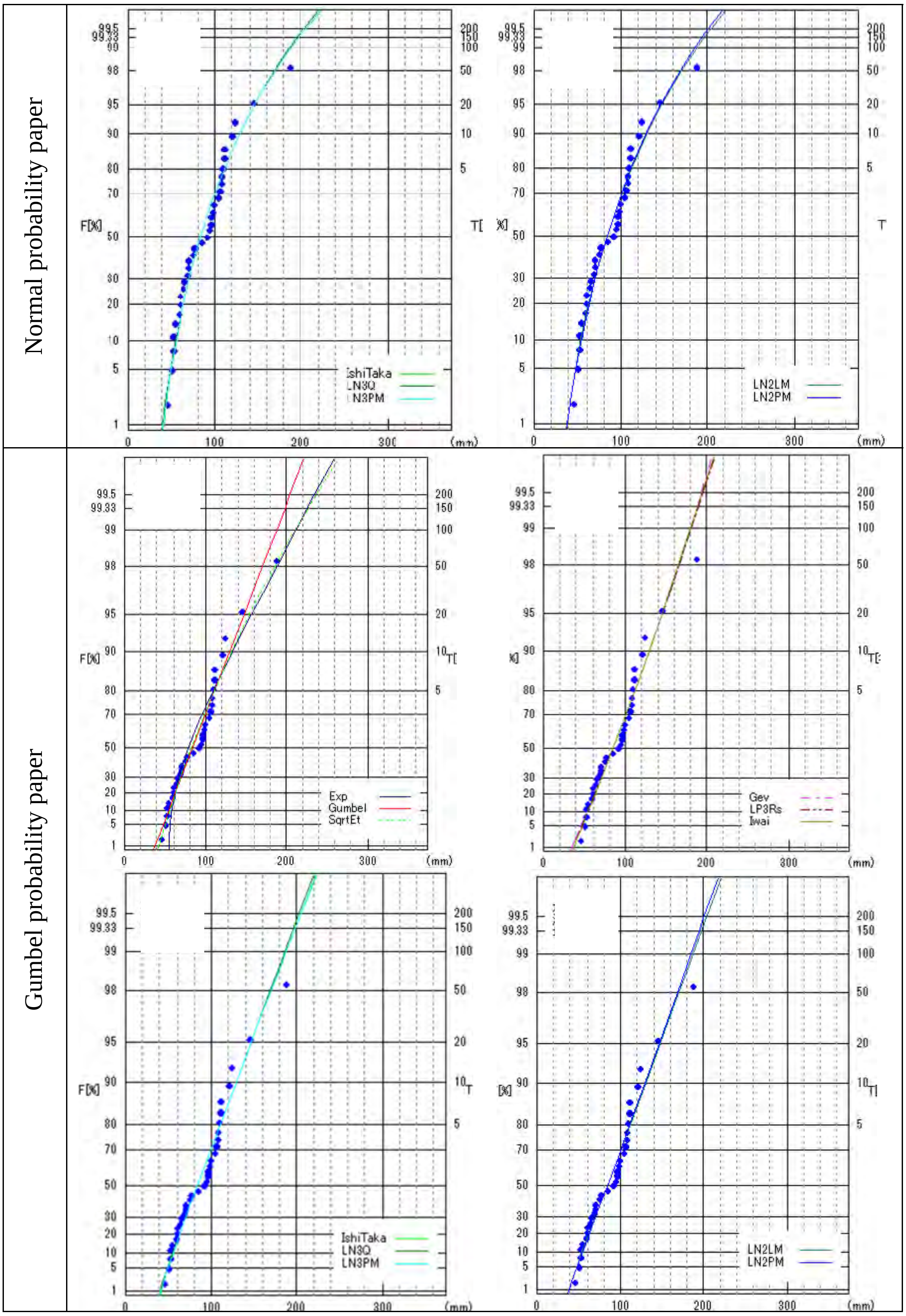
Jack Knife Error	Return	Exp	Gumbel	SqrtEt	Gev	LP3Rs	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
	2-yr	4.7	5	5	6.2	83.1	6.9	5.7	6.9	5.7	5	5
	5-yr	7.5	7.8	8.1	7.6	110.1	8.1	7.3	7.8	7.4	7.5	7.6
	10-yr	10.6	10.1	10.7	10.7	127.4	9.8	11.3	10.8	11.3	9.9	10.1
	25-yr	14.9	13.3	14.6	18.3	148.8	14.3	19.6	19	19.6	13.4	13.6
	50-yr	18.3	15.8	17.8	26	164.6	19.2	27.6	27.3	27.5	16.3	16.5
	80-yr	20.7	17.5	20.1	32	175.3	23.1	33.7	33.8	33.5	18.4	18.5
	100-yr	21.8	18.3	21.3	35	180.4	25.1	36.7	37.1	36.5	19.4	19.5

Source: JICA Survey Team



Source : JICA Survey Team

Figure 3.4.1 Result of Frequency Analysis for Annual Maximum Basin Mean 1-day Rainfall (1/2)



Source : JICA Survey Team

Figure 3.4.1 Result of Frequency Analysis for Annual Maximum Basin Mean 1-day Rainfall (2/2)

(2) Partial Duration Series of Basin Mean 1-day Rainfall

Through 32years from 1980 to 2012 exclusive of 2003 because of inconsistency in terms of the order of water level and annual maximum rainfall, top 100 and over 50mm 1-day rainfall are obtained as shown in Table 3.4.4.

Table 3.4.4 Partial Duration Series Basin Mean 1-day Rainfall

Year	1-day (mm)	Year	1-day (mm)	Year	1-day (mm)	Year	1-day (mm)
01/29/1982	60.8	1996/06/03	100.2	04/23/2000	69.6	2008/12/06	86.7
01/30/1982	73.6	1996/06/11	70.3	06/05/2000	111.5	2009/01/02	106.0
03/19/1982	90.9	1996/08/29	89.6	06/20/2000	81.6	2009/04/17	60.9
10/03/1982	62.4	1996/09/30	78.8	07/24/2000	63.5	2009/08/27	69.1
01/04/1985	70.2	1996/10/07	60.7	11/13/2000	67.6	2009/11/24	145.8
10/23/1988	65.4	1996/11/24	61.2	11/30/2000	65.0	2010/06/12	72.3
07/17/1989	70.5	1997/04/13	98.5	12/08/2000	64.3	2010/06/21	75.9
11/07/1990	62.0	1997/10/31	92.4	03/27/2001	63.3	2010/07/06	124.2
11/12/1990	121.4	1998/06/23	61.4	05/08/2001	61.5	2010/07/11	64.4
04/24/1991	108.4	1998/08/21	74.0	08/12/2001	74.5	2010/07/21	75.6
07/28/1992	60.6	1998/09/15	70.1	09/28/2001	64.8	2010/07/22	86.2
01/15/1993	68.4	1998/11/09	106.9	11/21/2001	95.2	2010/08/18	62.4
02/01/1993	63.4	1999/01/08	93.5	06/15/2002	68.0	2010/10/08	85.5
06/30/1993	74.5	1999/02/05	106.3	06/19/2002	96.7	2010/11/21	83.9
09/13/1993	62.9	1999/03/05	69.2	05/31/2004	73.9	2011/01/13	62.9
12/25/1993	60.8	1999/05/29	69.4	04/23/2000	85.7	2011/01/15	88.9
12/26/1993	77.4	1999/09/24	77.8	06/13/2005	63.4	2011/01/31	66.2
06/13/1994	75.5	1999/12/07	88.7	12/07/2005	64.9	2011/05/23	71.4
08/21/1995	80.9	1999/12/18	65.6	06/26/2007	68.3	2011/06/13	107.5
08/30/1995	68.2	1999/12/22	104.6	04/26/2008	78.0	2011/07/02	61.8
09/11/1995	64.8	2000/02/03	99.9	04/27/2008	83.3	2011/09/01	70.9
12/26/1995	104.6	2000/02/11	66.1	04/28/2008	64.2	2011/11/14	63.9
12/27/1995	107.5	2000/03/11	74.3	06/29/2008	66.4	2011/12/16	187.2
02/05/1996	65.3	2000/04/05	70.7	08/20/2008	109.1	2012/02/19	65.8
04/10/1996	72.9	2000/04/19	66.6	11/10/2008	69.0	2012/12/04	111.7

Source: JICA Survey Team

Considering that value of SLSC and visual fitness with the distribution curve as well as Jack-knife method, the Generalized Pareto Distribution (GP) was concluded the most appropriate for the statistical analysis. The SLSC value and correlation coefficient as well as JackKnife's estimate and error are shown in Table 3.4.5.

The return period of the rainfall during TS. Sendon is estimated 57 year return period as shown in Table 3.4.5. Figure 3.4.2 presents the probable distribution plotting on some probability paper of each distribution. The return period of the rainfall during TY Pablo was estimated at 14 year return period according to TY Pablo's rainfall which was separated in 2-day (4^{th} December. is 111.7mm, 5^{th} December. is 27.8mm) and totaled 139.5mm.

From a point of view of SLSC, the partial duration series analysis is better fitted than annual maximum series. Therefore, the partial duration series was adopted.

Table 3.4.5 Results of Frequency Analysis for Partial Duration Series of Basin Mean 1-day Rainfall

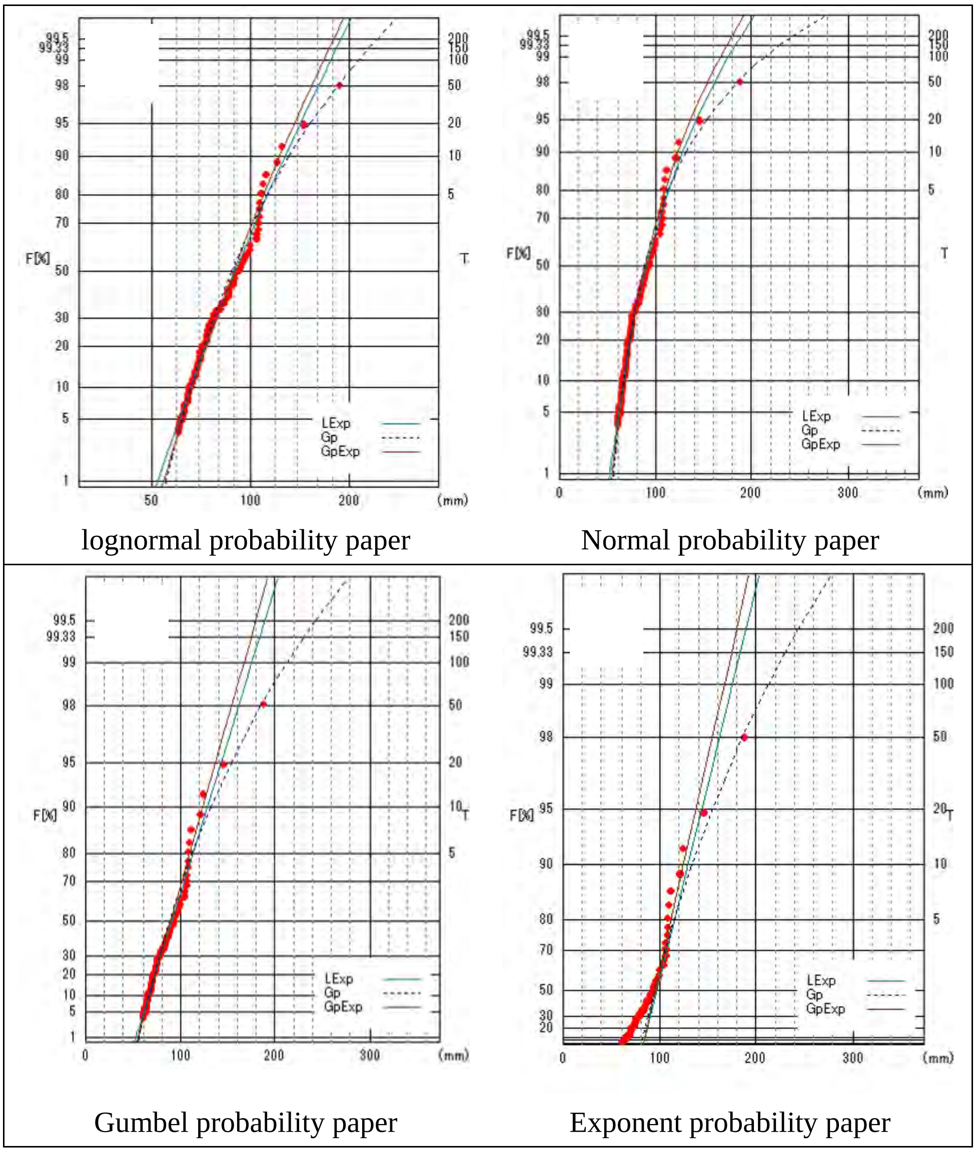
1-day Basin Mean Rainfall(mm)			
	Lexp	Gp	GpExp
X-COR(99%)	0.987	0.988	0.987
P-COR(99%)	0.995	0.998	0.996
SLSC(99%)	0.036	0.031	0.046
Log Likelihood	-401.4	-393	-393.4
pAIC	806.7	792	790.8
X-COR(50%)	0.976	0.98	0.976
P-COR(50%)	0.99	0.986	0.988
SLSC(50%)	0.059	0.042	0.074

Probability	Return P	Lexp	Gp	GpExp
	2-yr	90.4	88.2	89.5
	5-yr	113.4	113.2	110.8
	10-yr	128.7	132.2	124.9
	25-yr	148	159.7	142.8
	50-yr	162.3	182.8	156
	80-yr	172	199.8	164.9
	100-yr	176.6	208.3	169.1
	Sendong / Pablo 187.2 / 139.5 mm			
	Sendong	Over100yr	57yr	Over100yr
	Pablo	17yr	14yr	21yr

Jack Knife Estimate	Return P	Lexp	Gp	GpExp
	2-yr	90.4	88.4	89.6
	5-yr	113.4	113.5	111
	10-yr	128.7	132.3	125.1
	25-yr	148	158.8	143.1
	50-yr	162.3	180.4	156.3
	80-yr	172	195.9	165.3
	100-yr	176.6	203.5	169.5
	Sendong / Pablo 187.2 / 139.5 mm			
	Sendong	Over100yr	63yr	Over100yr
	Pablo	17yr	14yr	21yr

Jack Knife Error	Return P	Lexp	Gp	GpExp
	2-yr	3.3	3.3	3.2
	5-yr	6.0	5.9	5.5
	10-yr	7.8	9.2	7.0
	25-yr	10.2	16.2	9.0
	50-yr	11.9	24.1	10.4
	80-yr	13	30.8	11.4
	100-yr	13.6	34.5	11.9

Source: JICA Survey Team



lognormal probability paper | Normal probability paper

Gumbel probability paper | Exponent probability paper

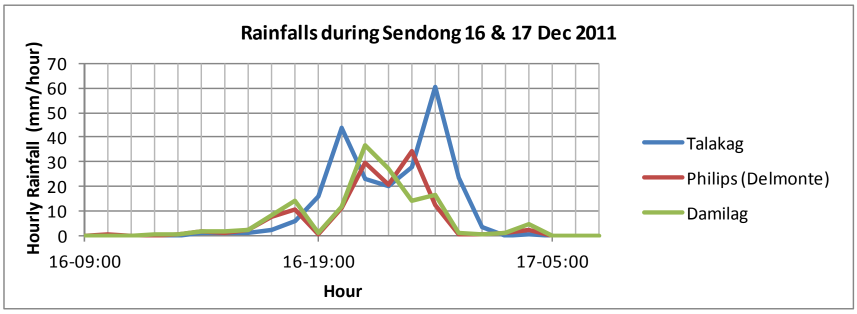
Source : JICA Survey Team

Figure 3.4.2 Result of Frequency Analysis for Partial Duration Series of Basin Mean 1-day Rainfall

(3) Probable Rainfall Distribution of Sendong

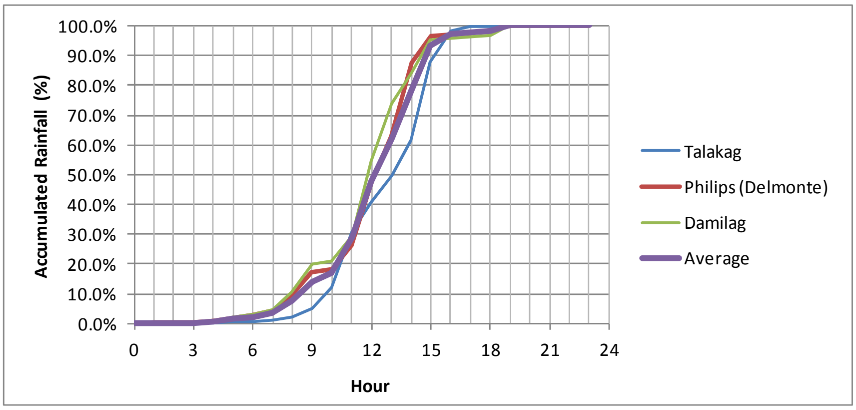
The hourly rainfall data during TS. Sendong in December 2011 were recorded at three(3) stations, i.e.Talakag, Damilag and Philips(PHI) in the vicinity of the CDO River basin.

Observed hourly rainfall records at the said three(3) stations are shown in Figure 3.4.3. Hourly rainfall distribution of the three records are shown in Figure 3.4.4 together with the mean of the three.



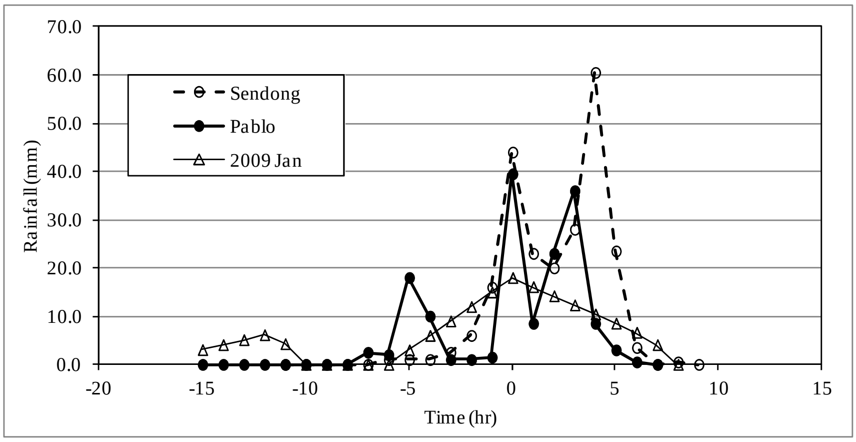
Source: JICA Survey Team

Figure 3.4.3 Observed Hourly Rainfall Record Observed at Three Rainfall Stations during TS.Sendong



Source: JICA Survey Team

Figure 3.4.4 Hourly Rainfall Distribution during TS.Sendong

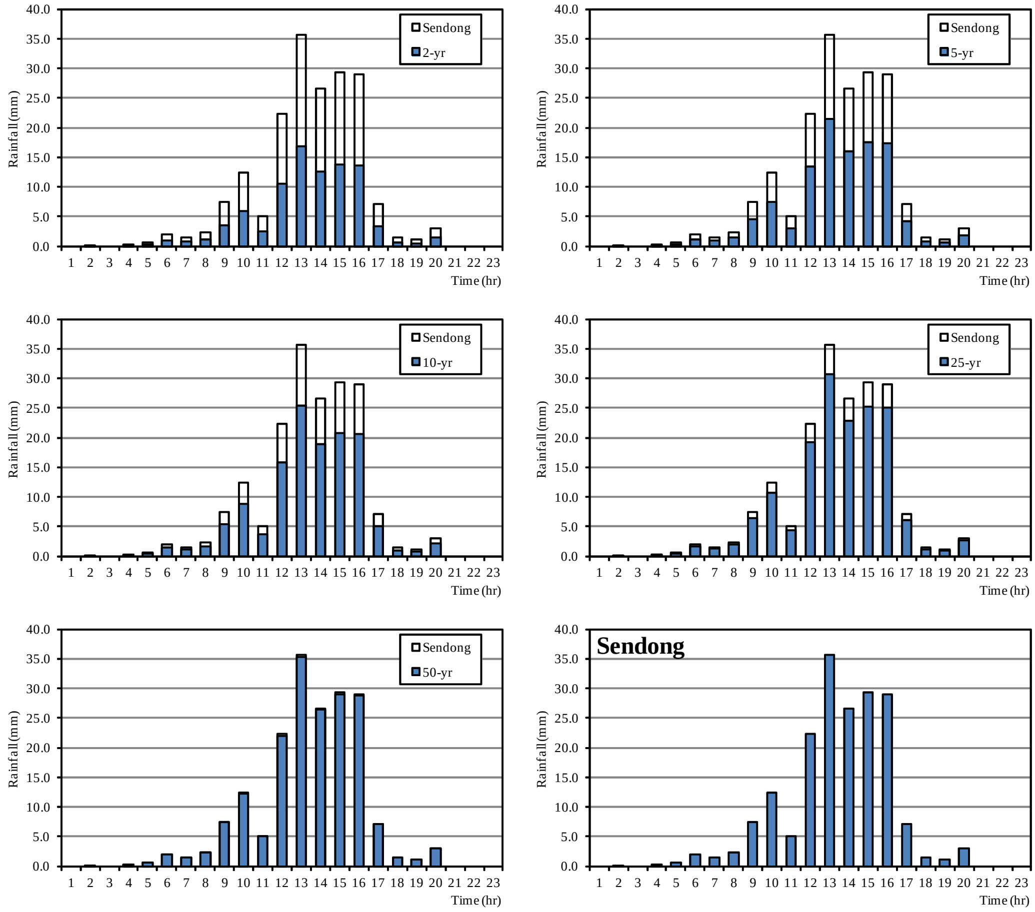


Source: JICA Survey Team

Figure 3.4.5 Rainfall Distribution of the Recent Stormy Rainfall

Figure 3.4.5 shows rainfall distribution during TS.Sendong and TY.Pablo at Talakag Station, respectively, together with that during TY. Ondoy(Jan. 2009 at Malaybalay Station). Rainfall duration in those typhoon and tropical storm were within 24 hours.

Average rainfall distribution during TS. Sendong shown in Figure 3.4.5 was applied to every stations available in 2011, which stations were used for Thiessen pattern t-12 as shown in Appendix P in DATA BOOK (Thiessen Pattern t-12). Hourly rainfall of each return period (2-yr, 5-yr, 10-yr, 25-yr, 50-yr) was estimated based on the hourly rainfall during TS. Sendong with a depletion rate. Estimated hyetograph of each return period is shown in Figure 3.4.6.



Source: JICA Survey Team

Figure 3.4.6 Probable Hourly Rainfall Pattern

CHAPTER 4 RUNOFF ANALYSIS

4.1 Runoff Model

Referring to the previous several related studies having been conducted in the Philippines, the Storage Function Model is applied for the runoff analysis in the Survey.

(1) Storage Function Model

Basic equations of the Storage Function Model are composed of continuity equation and equation of motion. The runoff is computed as phenomena of a network of basins and channels in the Storage Function Model.

1) Basic storage function for basin

The following function is assumed between the storage volume (S) of a basin and the runoff discharge (Q) and this equation is used as the equation of motion.

$$S_l = KQ_l^{\,p}$$

where, *l* and *p* : constants

Runoff computation is made using the above equation of motion and the following continuity equation for a basin.

$$\frac{dS_l}{dt} = \frac{1}{3.6} f \cdot r_{ave} \cdot A - Q_l$$

where,

f	:	inflow coefficient,
r_{ave}	:	basin mean rainfall (mm/hr),
A	:	catchment area (km^2),
$Q_l = Q(t + T_l)$	:	direct runoff discharge (m^3/s) from a basin at time of delay,
S_l	:	apparent storage volume (m^3/s hr) in a basin
T_l	:	time of delay.

The inflow coefficient is explained by primary coefficient f_1 and saturation rainfall R_{sa}. When rainfall starts, runoff occurs at the area of f_1*A, but accumulated rainfall exceeds the saturation rainfall R_{sa}, runoff occurs in all of the area.

2) Basic storage function for river channels

The equation of motion for a river channel and the continuity equation for channels are as follows:

$$S_l = KQ_l^{\,p} - T_l Q_l$$

$$\frac{dS}{dt} = \sum_{j=1}^{n} f_j I_j - Q_l$$

where,	*l* and *p*	:	constants of river course
	T_l	:	delay of time for river course.
	l_j	:	inflow discharge group, which flows into the channel from basins, tributaries and/or upper end of the channel,

f_j : inflow coefficient of each inflow,

$Q_l = Q(t + T_L)$: discharge (m^3/s) at the lower end of the channel where time of delay is considered,

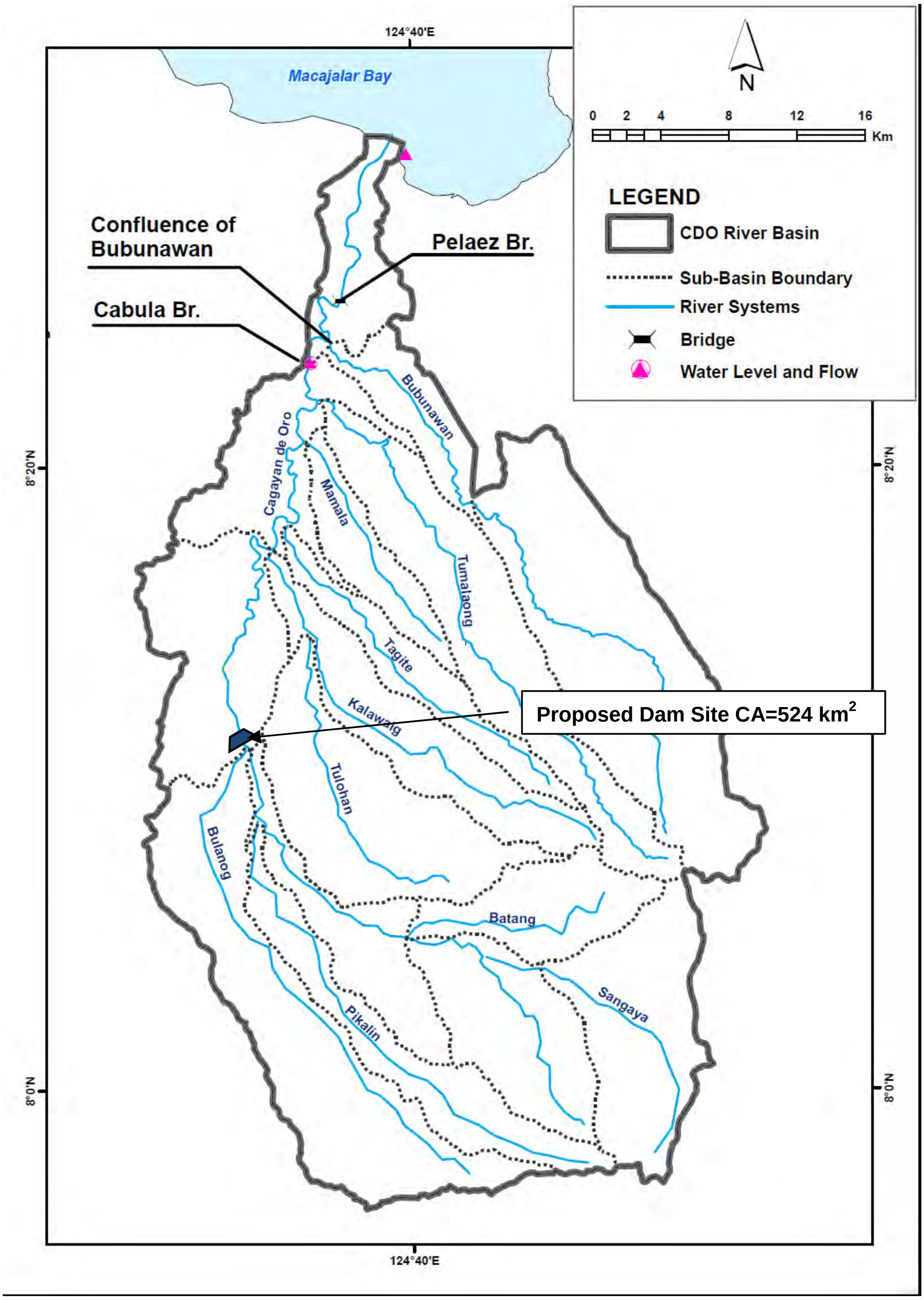
S_1 : apparent storage volume (m^3/s hr) in the channel, and

T_L : lag time

(2) Basin Division and Runoff Model.

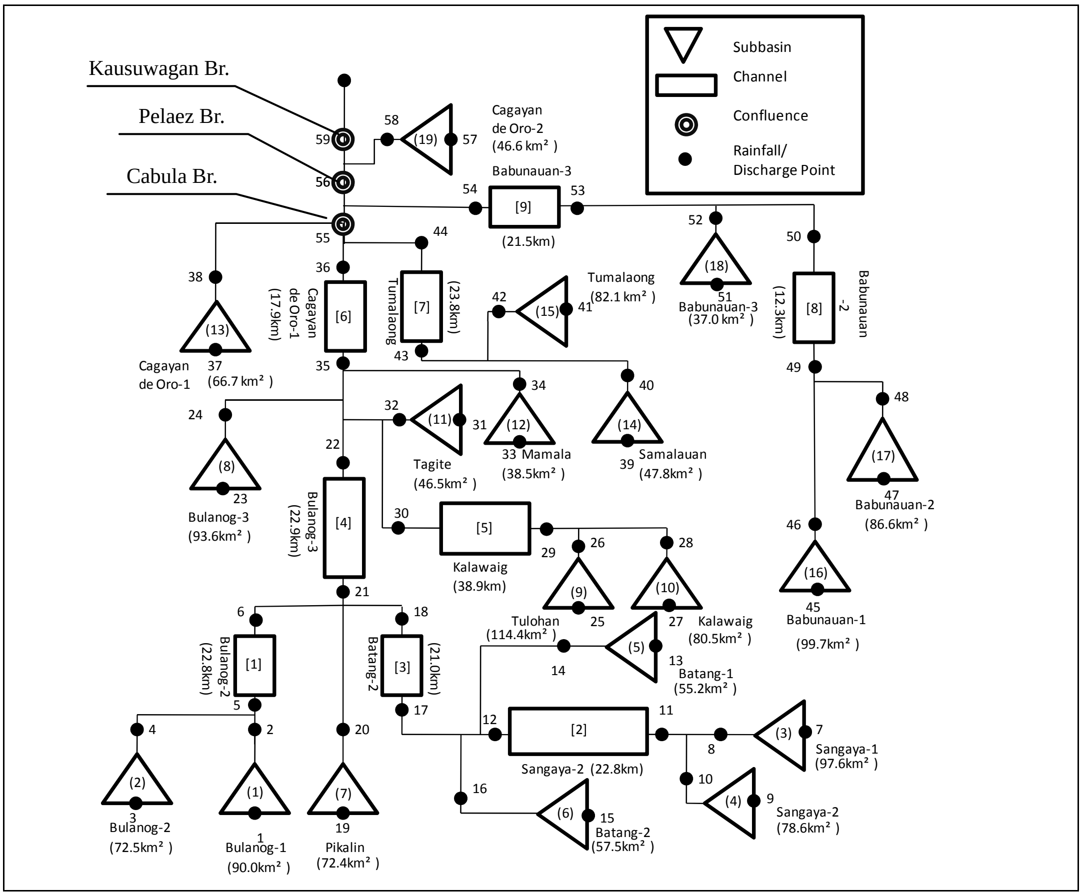
Total catchment area of the Cagayan de Oro River(CDO River) is 1,364 km^2 as shown in Figure 4.1.1. The total area are divided into 19 sub-basins and 10 channels dividing whole basin by major tributaries and additional segmentation when a subbasin has a long shape, which is shown in Figure 4.1.2 to be served as the runoff model diagram.

Considering the available observed flow at Cabula Bridge with a catchment area of 1,094 km^2, a runoff model has been calibrated at the Cabula Bridge point as shown in Figure 4.1.1 including 15 sub-basins.



Source : JICA Survey Team

Figure 4.1.1 Cagayan de Oro River Basin (C.A = 1,364 km^2)



Source : JICA Survey Team

Figure 4.1.2 Runoff Model Diagram for Cagayan de Oro River Basin

(3) Parameter Setting

i) Basin model parameter

$$K = 43.4 \cdot C \cdot I^{-1/3} \cdot L^{1/3}$$

$$p = 0.33 \quad (=1/3)$$

$$T_L = 0.047 \cdot L - 0.57 \quad (L \geq 11.9)$$
$$T_L = 0 \quad (L < 11.9)$$

where,	C	:	lzzard coefficient by land use,
	I	:	slope of river basin,
	L	:	length of river basin (km),
	T_L	:	time of delay (hr).

C have a value of 0.12 at mountain watershed and 0.012 at urban area. Regarding runoff coefficient, f_1 is fixed at 0.5.

ii) Channel model parameter

$$K = 0.166 \cdot L \cdot I^{-0.5}$$

$$p = 0.6$$

$$T_L = 7.36 \cdot 10^{-4} \cdot L \cdot I^{-0.5}$$

where, L : channel length (km),
I : channel slope,
T_L : time of delay (hr).

iii) Initial runoff coefficient (fl)

Runoff coefficient f_1 is fixed at 0.5.

iv) Summary of Parameters

Tables 4.1.1 and 4.1.2 show parameters of sub-basin and channel, respectively computed based on the equation described in i) and ii) above.

Table 4.1.1 Parameters for Sub-Basin

No.	Sub-Basin	Area A (km2)	Length of RC L (km)	High EL. (m)	Low EL. (m)	1/Slope	Nature (%)	Urban (%)	Rough C	K	P	TL (hr)
1	Bulanog-1	90.0	25.5	1750	830	27.7	99.9 %	0.1 %	0.12	46.3	0.3	0.6
2	Bulanog-2	72.5	23.1	1000	380	37.2	100.0 %	0.0 %	0.12	49.5	0.3	0.5
3	Sangaya-1	97.6	21.4	2763	920	11.6	100.0 %	0.0 %	0.12	32.7	0.3	0.4
4	Sangaya-2	78.6	24.6	2260	650	15.3	100.0 %	0.0 %	0.12	37.6	0.3	0.6
5	Batang-1	55.2	20.1	2480	650	11.0	100.0 %	0.0 %	0.12	31.5	0.3	0.4
6	Batang-2	57.5	30.5	1240	380	35.4	100.0 %	0.0 %	0.12	53.4	0.3	0.9
7	Pikalin	72.4	45.0	2560	460	21.4	100.0 %	0.0 %	0.12	51.4	0.3	1.6
8	Bulanog-3	93.7	26.9	1120	140	27.5	99.9 %	0.1 %	0.12	47.1	0.3	0.7
9	Tulohan	114.4	37.3	1800	250	24.0	99.9 %	0.1 %	0.12	50.1	0.3	1.2
10	Kalawaig	80.6	39.5	1860	140	23.0	99.8 %	0.2 %	0.12	50.3	0.3	1.3
11	Tagite	46.5	32.2	1560	100	22.1	100.0 %	0.0 %	0.12	46.5	0.3	1.0
12	Mamala	38.5	27.6	700	60	43.2	100.0 %	0.0 %	0.12	55.2	0.3	0.7
13	Cagayan de Oro-1	66.7	14.2	820	50	18.5	99.3 %	0.8 %	0.12	33.1	0.3	0.1
14	Samalauan	47.8	21.8	2560	460	10.4	100.0 %	0.0 %	0.12	31.7	0.3	0.5
15	Tumalaong	82.1	31.8	980	60	34.6	99.9 %	0.1 %	0.12	53.7	0.3	0.9
16	Bubunauan-1	99.7	23.4	2600	560	11.5	100.0 %	0.0 %	0.12	33.6	0.3	0.5
17	Bubunauan-2	86.6	21.4	1020	300	29.7	100.0 %	0.0 %	0.12	44.7	0.3	0.4
18	Bubunauan-3	37.1	22.9	470	40	53.3	100.0 %	0.0 %	0.12	55.6	0.3	0.5
19	Cagayan de Oro-2	46.6	15.9	240	0	66.2	56.6 %	43.4 %	0.07	32.3	0.3	0.2
	Total / Average	1363.8	505.1	1568	338	27.5	97.7 %	2.3 %				

Source: the Survey Team

Table 4.1.2 Parameters for Channels

No.	Channel	Length L (km)	High EL. (m)	Low EL. (m)	1/Slope	K	P	TL (hr)
1	Bulanog-2	22.8	830	380	50.7	27.0	0.6	0.1
2	Sangaya-2	22.8	1900	650	18.3	16.2	0.6	0.1
3	Batang-2	21.0	650	380	77.9	30.8	0.6	0.1
4	Bulanog-3	22.9	380	140	95.6	37.2	0.6	0.2
5	Kalawaig	38.9	1520	140	28.2	34.2	0.6	0.2
6	Cagayan de Oro-1	17.9	140	50	198.8	41.9	0.6	0.2
7	Lumalaong	23.8	460	60	59.6	30.5	0.6	0.1
8	Bubunauan-2	12.3	560	300	47.4	14.1	0.6	0.1
9	Bubunauan-3	21.5	300	40	82.6	32.4	0.6	0.1
10	Cagayan de Oro-2	19.4	140	0	138.5	37.9	0.6	0.2
	Total / Average	223.4	688	214	79.7			

Source: JICA Survey Team

v) Base flow

Base flow is estimated at 103 m^3/s (0.1 $m^3/s/km^2$) based on the daily discharge record mentioned in 2.3 (3) and which is shown in Appendix P in DATA BOOK. The base flow was calculated by average of 21years daily discharge estimated from observed water level by rating curve in Figure 4.2.3.

4.2 Simulation of Discharge Hydrograph during Sendong at Cabula Bridge

4.2.1 Discharge Measurement at Cabula Bridge and Peak Discharge during Sendong

DPWH provided water level-discharge measurement record[1]. Discharge measurement have been carried out for low water stage of less than 300m^3/sec. A relationship between observed water levels and discharges was developed and expressed in form of the following equation:

$$Q=a\,(h - h_0)^n$$

where, Q : Discharge (m^3/s),

h : Gauge reading height (m),

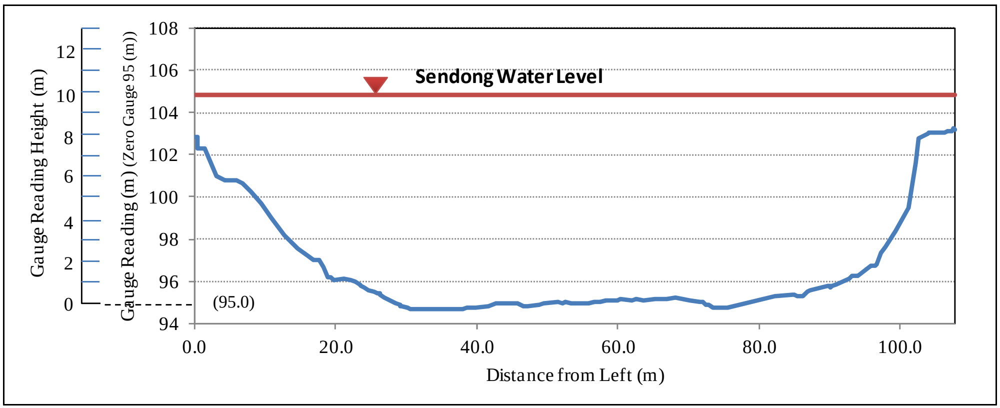
h_0 : Gauge height corresponding to zero flow (computed; m),

a and n : Constants.

As shown in Figure 4.2.1, the gage 0 height is equivalent to El.95.0 m(based on a TBM locally set at on the deck slab of the bridge; TBM at El.104 m)

TBM at El.104 m is equivalent to El.48.70m(MSL) in accordance with the current river profile and cross-section survey conducted in the Survey.

Consequently, Gage "0" height is equivalent to El.39.70m(MSL)



Source: JICA Survey Team based on the survey by DPWH in 2008.

Figure 4.2.1 River Cross Section at Cabula Bridge

4.2.2 Estimation of discharge at Cabula Bridge based on the observation during TY. Pablo

(1) Measurement of flow velocity during TY. Pablo

Flood discharge during Typhoon Pablo at the Ysalina Bridge was estimated based on a video images by measurement of moving distance and time of floating objects in the video image. It was recorded at around 14:30 on December 4, 2012 before the flood peak time.

1) Flow velocity

a) Surface flow velocities of 12 lines

The surface flow velocities of 12 lines were estimated by observing 12 floating objects as shown in the photo below and summarized in the table below:

[1] At the Cabula Bridge for a period of 2001-2011 together with cross-section survey data at a bridge section conducted in July 2008

Note: The number, “S”, and “E” in the photo denote Object No., start time and end time, respectively.

Source: JICA Survey Team

Object No.	Distance (m)	Start Time (mm:ss.sss)	End Time (mm:ss.sss)	Time Difference (sec)	Surface Flow Velocity (m/s)
01	13.93	01:35.533	01:40.638	5.105	2.73
02	8.68	02:58.487	03:00.492	2.005	4.33
03	13.57	00:07.292	00:12.215	4.923	2.76
04	6.53	00:00.364	00:02.370	2.006	3.26
05	20.98	00:03.281	00:08.386	5.105	4.11
06	17.59	00:13.491	00:17.502	4.011	4.39
07	14.06	00:16.955	00:20.784	3.829	3.67
08	10.02	01:08.186	01:10.655	2.469	4.06
09	15.94	01:34.074	01:38.460	4.386	3.63
10	15.57	01:26.053	01:30.428	4.375	3.56
11	18.45	01:40.456	01:45.013	4.557	4.05
12	31.12	00:05.287	00:15.581	10.294	3.02
Average	---	---	---	---	3.63

Source: JICA Survey Team

***** Object-01 *****

Time: 01:35.533

Time: 01:40.638

***** Object-02 *****

Time: 02:58.487

Time: 03:00.492

***** Object-03 *****

Time: 00:07.292

Time: 00:12.215

***** Object-04 *****

Time: 00:00.364

Time: 00:02.370

***** Object-05 *****

Time: 00:03.281

Time: 00:08.386

***** Object-06 *****

Time: 00:13.491

Time: 00:17.502

***** Object-07 *****

Time: 00:16.955

Time: 00:20.784

***** Object-08 *****

Time: 01:08.186

Time: 01:10.655

***** Object-09 *****

Time: 01:34.074

Time: 01:38.460

***** Object-10 *****

Time: 01:26.053

Time: 01:30.428

***** Object-11 *****

Time: 01:40.456

Time: 01:45.013

***** Object-12 *****

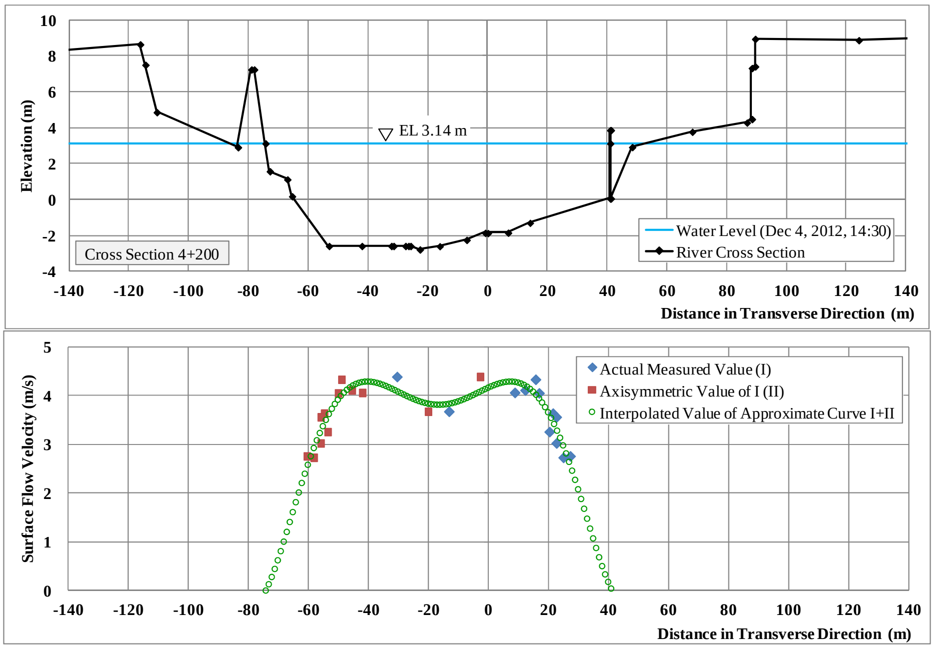
Time: 00:05.287

Time: 00:15.581

Source: JICA Survey Team

b) Average surface flow velocity and distribution

The water level at the video recording time was estimated at EL 3.14 m as mentioned in the clause 2) later. Assuming that velocities at the both banks were almost zero based on the video image, approximate distribution of surface velocity is shown in the figure below. Average of the surface velocity was calculated at 3.21 m/s, which was the representative value of surface flow velocity at this cross section.



Source: JICA Survey Team

c) Correction factor of surface flow velocity

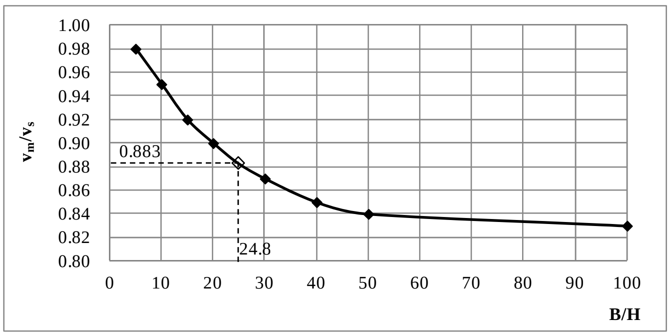
To correct surface flow velocity into mean flow velocity, the method for surface float measurement was applied for this case. The correction factor of surface flow velocity was determined by the table below by using width of water surface and mean water depth.

B/H	5	10	15	20	30	40	50	100
Vm/Vs	0.98	0.95	0.92	0.90	0.87	0.85	0.84	0.83

Note: B = width of water surface, H = mean water depth, Vm = mean velocity, Vs= surface velocity
Source: The Correction of Hydraulic Formulae (Japan Society of Civil Engineers 1963, 1971)

The correction factor was determined to be 0.883 as follows:

B/H = 115.34 (m) / 4.65 (m) = 24.8



Source: JICA Survey Team

d) Mean flow velocity

The mean flow velocity was therefore estimated at 2.84 m/s (= 3.21 x 0.883).

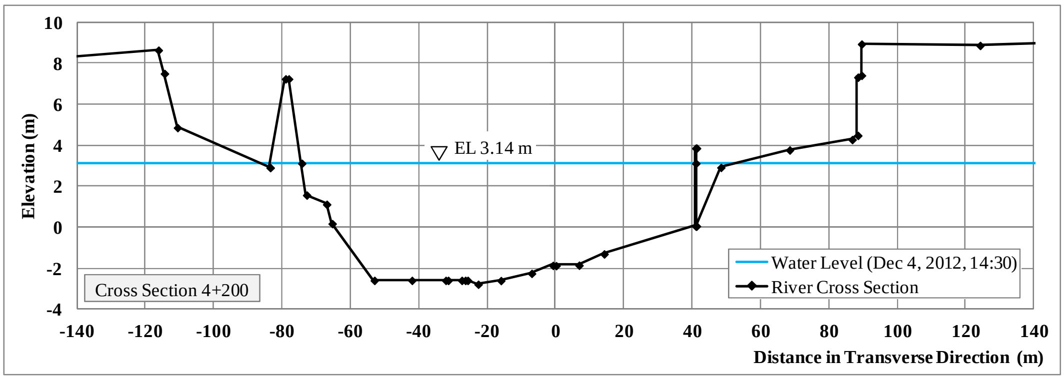
2) Water level

The water level at the time of video recording was estimated for some downstream side of the Ysalina Bridge in order to disregard an influence of backwater around the piers. The estimated point is shown in the photo below as the point (B). The point (A) shown in the photo is a reference point for measuring the height at the point (B) because the size of bridge is exactly known. By comparing the height of structures at each two point and using the result of cross section survey, the water level was estimated at EL 3.14 m.

Source: JICA Survey Team

3) Cross section area

Cross section area was estimated at 536.47 m^2 when the river water level is EL 3.14 m.



Source: JICA Survey Team

4) Discharge at video recording time

By applying the video animation taken at Yaslina Bridge during TY. Pablo, the flow velocity at Ysalina Bridge was estimated as follows:

Shooting Date and Time	at 14:30 on December 4, 2012 14 : 30
Mean Velocity（m/s）	2.84 m/s
Mean Discharge（m^3/s）	1,523 m^3/s

Discharge (m^3/s) = Mean Flow Velocity (m/s) x Cross Section Area (m^2)
= 2.84 (m/s) x 536.47 (m^2)
= 1,523 (m^3/s)

Location of the related bridges is shown in Figure 2.4.1.

(2) Presumption of Discharge at Cabula Bridge at Same Time of Discharge Estimation at the Ysalina Bridge

Discharge at the Cabula Bridge was computed at 1,223m^3/s by applying specific discharge based on the estimated discharge at Ysalina Bridge as follows:

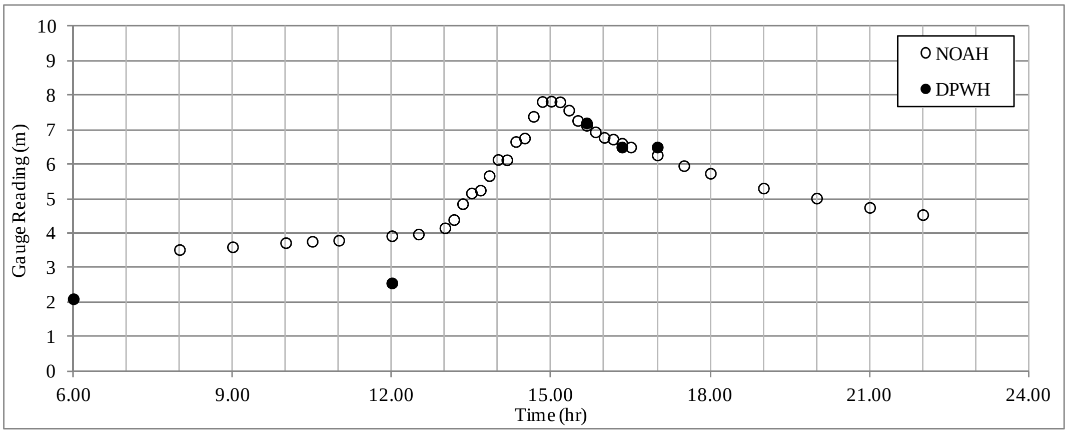
Location	Catchment Area (km^2)	Distance from River Mouth (km)	Discharge (m^3/s)	Specific Discharge ($m^3/s/km^2$)
Ysalina Bridge	1,362	4.20	1,523	1.118

(3) Lag Time of Food Flow from the Cabula Bridge to the Ysalina Bridge

The conveyance time of flood flow was estimated from the Cabula Bridge to the Ysalina Bridge to be about 1 hour that flow velocity of about 3 m/s take about 1 hour for a 14 km distance between the said two bridges.

(4) Observed water level at Cabula Bridge

The water level observation records are available at the Cabula Bridge after TS. Sendong, which were of observation at every 10 minutes by the self recording water level gauge by NOAH as well as gauge reading at three (3) times a day by DPWH(every 1 hour during flooding time). Every 1-hour observation by DPWH was not carried out during TY. Pablo. Water level was observed until 1 hour before that flood discharge rose because the observing system was driven by solar power that it switched over the interval to 1-hour from 10-minutes due to battery-saving in case that the weather was continually bad for a few days.



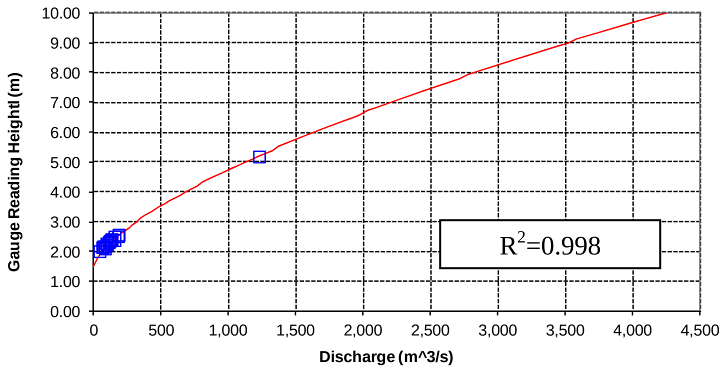
Source: JICA Survey Team

Figure 4.2.2 Water Level Observation Record at Cabula Bridge during TY. Pablo

Video animation shooting at the Yaslina Bridge during TY. Pablo was made at about 14:30 of December 4, 2012. Taking account of 1-hour time of flood flow between Cabula Bridge and Ysalina Bridge as estimated in iii) above, it was presumed that the discharge concerned(1,523m^3/s at the Pelaez Bridge and 1,223 m^3/s at Cabula Bridge) passed through the Cabula Bridge at about 13:30, when water level(gage reading height) was at about 5.2 m according to the NOAH water level observation.

(5) Water level and discharge curve at Cabula Bridge

The discharge measurement at the Cabula Bridge was carried out by DPWH. Out of those available records, the recent record from 2008 to 2011 after cross section survey(July 2008) were used for development of a water level and discharge curve incorporating additional discharge data obtained during TY. Pablo of 1,223 m^3/s at water level at 5.2 m. Consequently, the water level and discharge curve(formula) was expressed by $Q=170.4(h - 1.5)^{1.5}$ as shown in Figure 4.2.3.



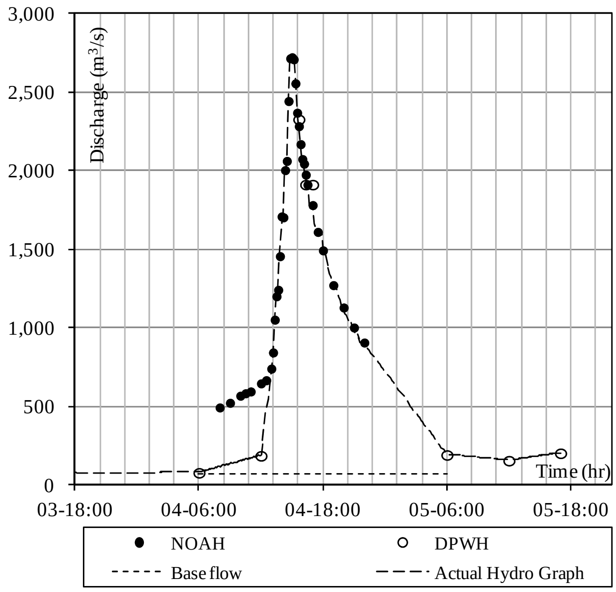
Source: JICA Survey Team

Figure 4.2.3 Water Level – Discharge Curve at Cabula Bridge(computed)

4.2.3 Flood Hydrograph and its Peak Discharge at Cabula Bridge during TY. Pablo

According to the observation record by NOAH during TY. Pablo, the highest water depth(gage reading height) was at 7.83 m, which is equivalent to about 2,700m^3/s in terms of peak discharge based on the computed water level – discharge curve.

However, the base flow calculated by NOAH data was estimated to be more than 450m^3/s which was considered too high value as a base flow as discussed in detail below. As for base flow, DPWH record was adopted and NOAH data were used from rising period as shown in Figure 4.2.4.



Source: JICA Survey Team

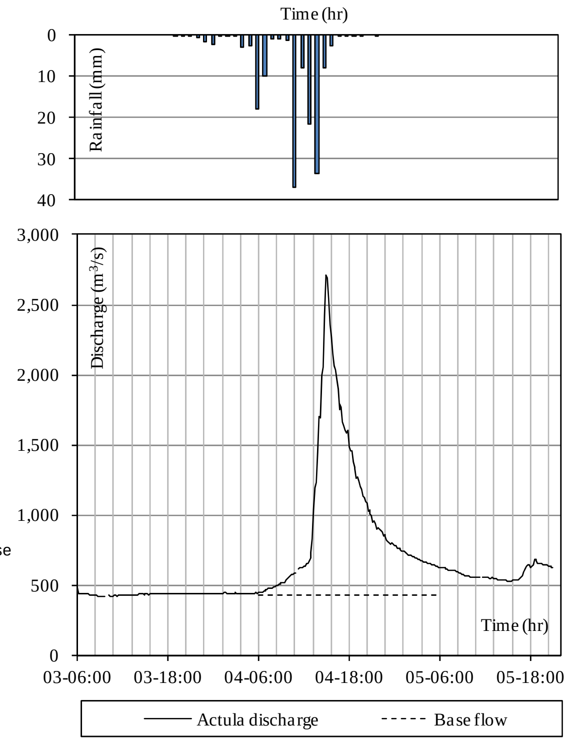
Figure 4.2.4 Discharge Hydrograph at Cabula Bridge during TY. Pablo

(1) Separation of Runoff Component

In order to determine the parameter of river sub-basin, direct runoff and base flow was estimated by separating the runoff component using the method of horizontal separation assuming base flow as constant before flood flow occurred.

As shown in the table below regarding that base flow was regarded as about 450m^3/s (1.48 mm/hr) before flood flow occurred at 6 am, 4th Dec.

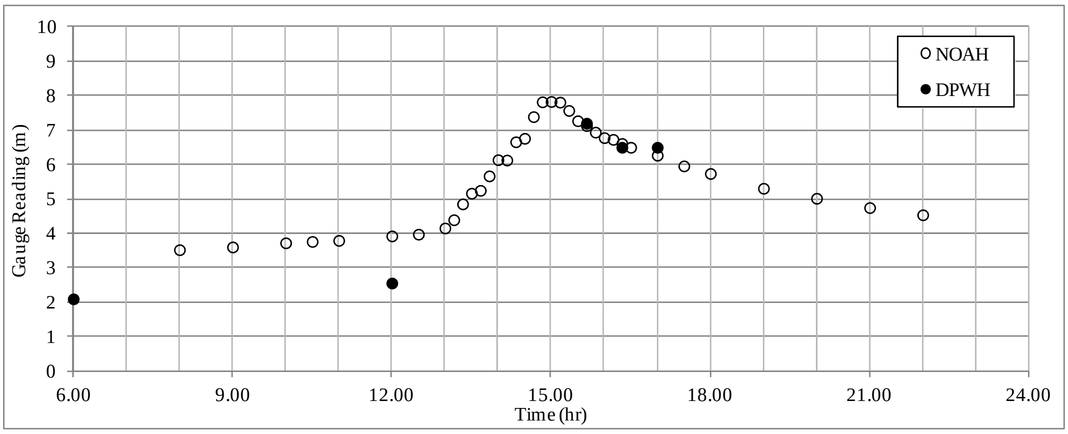
Date	Obs.Q m3/s	Obs.Q mm/hr	
2012/12/3 6:00	489	1.61	
2012/12/3 7:00	436	1.43	
2012/12/3 8:00	429	1.41	
2012/12/3 9:00	418	1.38	
2012/12/3 10:00			
2012/12/3 11:00	425	1.40	
2012/12/3 12:00	432	1.42	
2012/12/3 13:00	432	1.42	
2012/12/3 14:00	432	1.42	
2012/12/3 15:00	436	1.43	
2012/12/3 16:00	439	1.44	
2012/12/3 17:00	439	1.44	
2012/12/3 18:00	439	1.44	
2012/12/3 19:00	443	1.46	
2012/12/3 20:00	443	1.46	
2012/12/3 21:00	443	1.46	
2012/12/3 22:00	443	1.46	
2012/12/3 23:00	439	1.44	
2012/12/4 0:00	443	1.46	
2012/12/4 1:00	443	1.46	
2012/12/4 2:00	443	1.46	
2012/12/4 3:00	446	1.47	
2012/12/4 4:00	439	1.44	
2012/12/4 5:00	439	1.44	
2012/12/4 6:00	450	1.48	Start increase
2012/12/4 7:00	464	1.53	
2012/12/4 8:00	485	1.60	
2012/12/4 9:00	515	1.69	
2012/12/4 10:00	560	1.84	
2012/12/4 11:00	586	1.93	
2012/12/4 12:00	637	2.10	
2012/12/4 13:00	731	2.40	
2012/12/4 14:00	1698	5.59	
2012/12/4 15:00	2708	8.91	←Peak



Source: JICA Survey Team

(2) Comparison with DPWH Gauge R eading

The water level observation records are available at Cabula Bridge after TS Sendong, which was observed every 10 minutes by the self recording water level gauge by NOAH as well as gauge reading at three (3) times a day by DPWH (every 1 hour during flooding time).



Source: JICA Survey Team

- Discharge at 4th Dec. 6AM was regarded as a base flow.
- At 4th Dec. 6AM, the discharge from NOAH water level gauge was 450m^3/s and 51m^3/s from DPWH.

NOAH and DPWH recording method are summarized as shown below:

Observer	Equipment	Interval
Project NOAH	Ultrasonic	10 mins
DPWH Region X	Staff gauge	Daily (average of 3times record per day)

Source: JICA Survey Team

Recording from NOAH water level gauge have possibility of error in lower water level because NOAH gauge has possibility of reading error when the distance difference between the gauge and an object opens more than 10 – 12 m. For the Cabula bridge, distance between the lower water level and deck of bridge might be around 10 m and furthermore, the gauge is installed more than 1m above the deck.

(3) Consideration of Stream Flow Condition

Table below shows the stream flow condition of the Cagayan de Oro River during the past 20 years. Low water flow condition according to the observation record by DPWH was considered to be reasonable value according to 275-day and 355-day discharges, while NOAH record was considered reliable as a high flow data due to its continuous observation during flooding period.

75-day discharge	185-day discharge	275-day discharge	355-day discharge
119 m^3/s	94 m^3/s	76 m^3/s	61 m^3/s

Source: JICA Survey Team

(4) Highest Water Level and Peak Discharge in Sendong

It was estimated by using the water level – discharge curve shown in Figure 4.2.3 that the peak discharge in TS. Sendong at the Cabula Bridge was at 4,050 m^3/s which was corresponding to the gauge reading height of 9.8 m estimated by DPWH from flood mark and extrapolating of gauge.

4.3 Calibration of Runoff Model by Applying Observed Flood Data

(1) Assessment of Flood Runoff in Pablo

1) Rainfall pattern at the rainfall stations in and around the CDO River basin

Four rainfall stations have records of hourly rainfall during TY. Pablo including Talakag, Lumbia, Damilag and Malaybalay as shown in Figure 4.3.1 and 4.3.2. Those records are shown in Table 4.3.1. Because the Lumbia station had 3-hour rainfall data only, it was converted to 1-hour rainfall dividing by three (3).

2) Assessment of flood runoff in TY Pablo by applying Thiessen method

The basin mean rainfall was estimated through Thiessen method with the said four(4) rainfall stations of which Thiessen coefficient is shown in Figure 4.3.1.

A hydrograph simulated by the runoff model with the first basin parameter set up in 4.1 was assessed by a comparison with the discharge hydrograph based on the observed water level record at Cabula Bridge as shown in Figure 4.3.3.

The hydrograph obtained from the runoff model shows slow rising response, and a shape does not fit with that of the hydrograph obtained from observed data. Furthermore, it shows not clear response of runoff against corresponding rainfall.

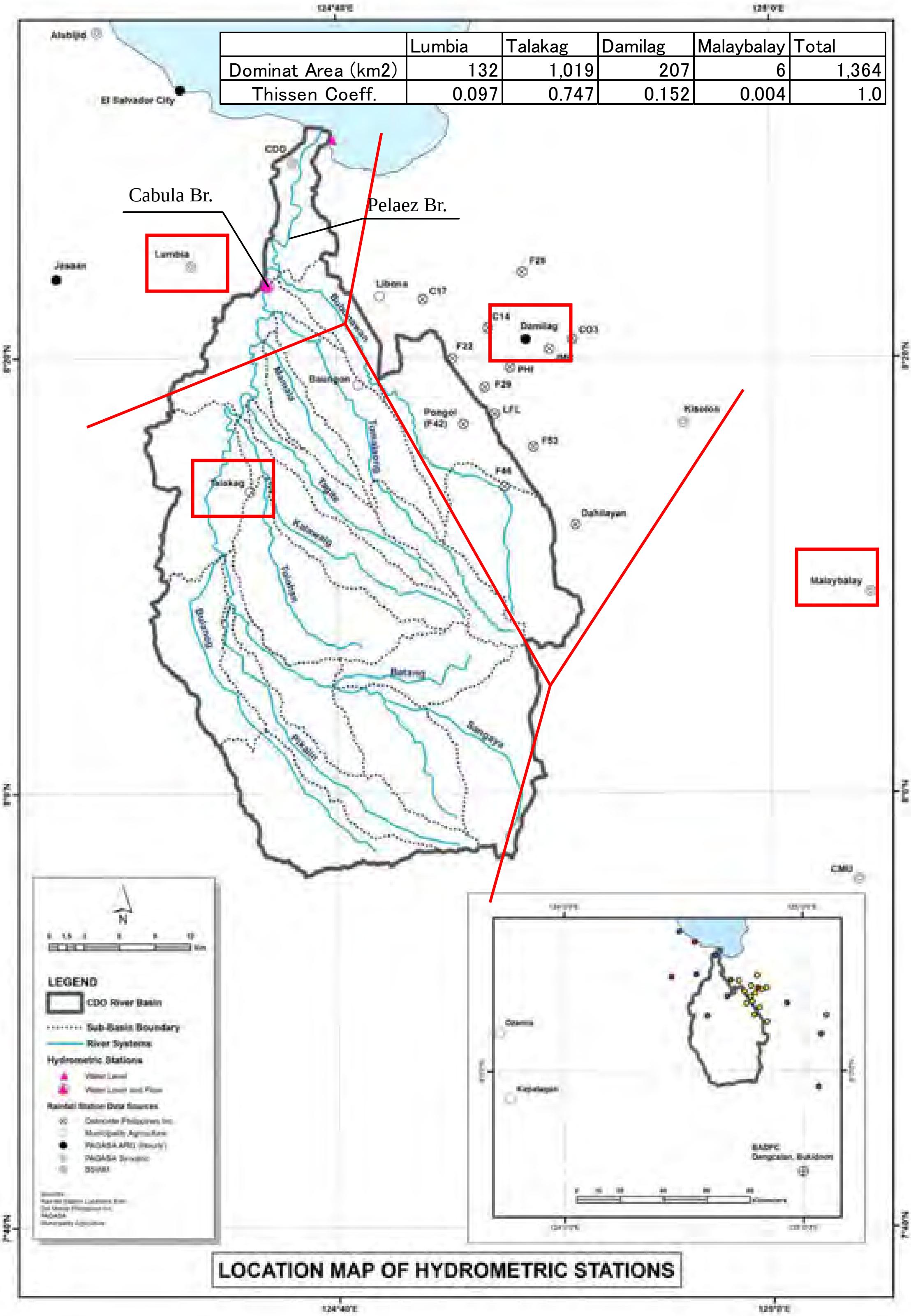
Hence, a second estimate of K and Rsa values were made in comparison with the discharge hydrograph based on the observed data in terms of peak discharge, peak occurrence time, a shape of hydrograph, so on, which result is shown in Figure 4.3.4.

Taking account of the discharge hydrograph based on the observed water level which shows quick response to rainfall, the K and Rsa values were adjusted as 0.5 time of the initial one and 110 mm, respectively.

Table 4.3.1 Hourly Rainfall Record during Pablo Observed at Four Stations

Date	Hourly Rainfall (mm/hour)			
	Talakag	Damilag	Lumbia	Malyabalay
12/03/2012 18:00	0.0	0	0.00	0.00
12/03/2012 19:00	0.0	0	3.00	2.30
12/03/2012 20:00	0.0	0	3.00	5.70
12/03/2012 21:00	0.0	0	3.00	7.30
12/03/2012 22:00	0.0	0	23.03	4.70
12/03/2012 23:00	0.5	0.5	23.03	2.00
12/04/2012 00:00	0.5	0.5	23.03	7.50
12/04/2012 01:00	0.0	0.0	4.77	2.60
12/04/2012 02:00	0.0	0.0	4.77	12.30
12/04/2012 03:00	0.0	0.0	4.77	37.10
12/04/2012 04:00	2.5	3.5	13.63	24.40
12/04/2012 05:00	2.0	4.5	13.63	13.80
12/04/2012 06:00	18.0	14.5	13.63	2.20
12/04/2012 07:00	10.0	5.5	4.03	1.60
12/04/2012 08:00	1.0	5.0	4.03	0.70
12/04/2012 09:00	1.0	6.0	4.03	0.70
12/04/2012 10:00	1.5	2.0	0.00	0.00
12/04/2012 11:00	39.5	9.5	0.00	0.00
12/04/2012 12:00	8.5	11.0	0.00	0.00
12/04/2012 13:00	23.0	31.0	0.00	0.00
12/04/2012 14:00	36.0	2.5	0.00	0.00
12/04/2012 15:00	8.5	2.5	0.00	0.00
12/04/2012 16:00	3.0	1.5	0.00	0.00
12/04/2012 17:00	0.5	1.0	0.00	0.00
12/04/2012 18:00	0.0	2.5	0.00	0.00
12/04/2012 19:00	0.0	0.5	0.00	0.00
12/04/2012 20:00	0.0	1.0	0.00	0.00
12/04/2012 21:00	0.0	0.0	0.00	0.00
12/04/2012 22:00	0.5	0.0	0.00	0.00
12/04/2012 23:00	0.0	0.0	0.00	0.00
Amount (mm)	156.5	105.0	145.4	124.9
Max (mm)	39.5	31.0	23.0	37.1

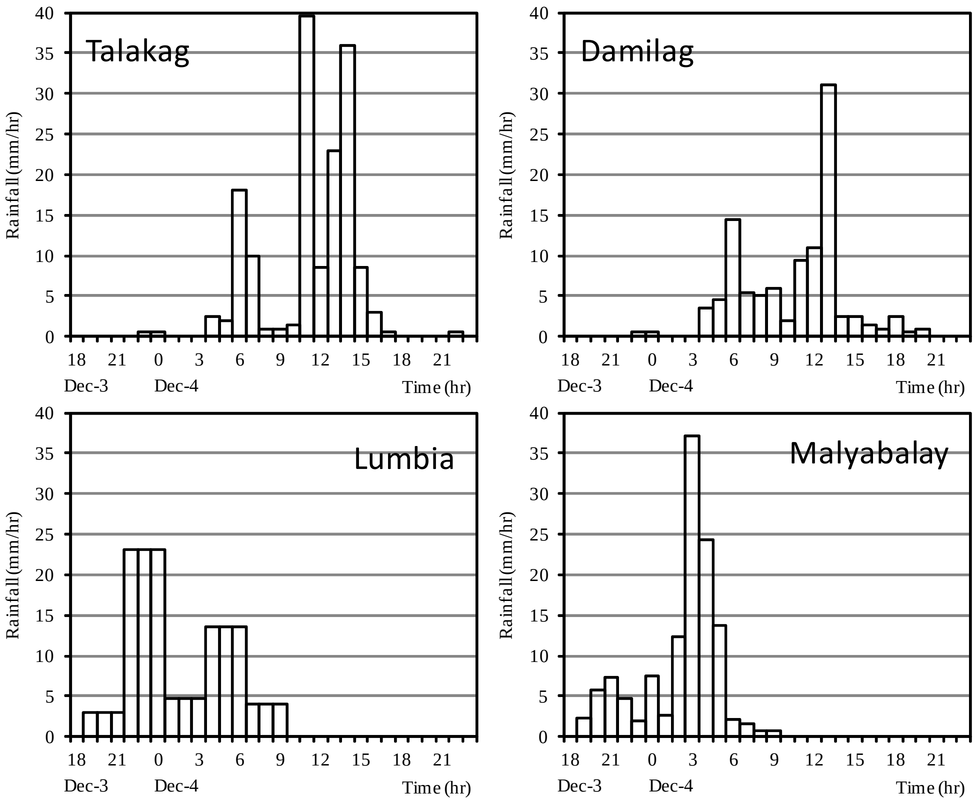
Source: JICA Survey Team



	Lumbia	Talakag	Damilag	Malaybalay	Total
Dominat Area (km2)	132	1,019	207	6	1,364
Thissen Coeff.	0.097	0.747	0.152	0.004	1.0

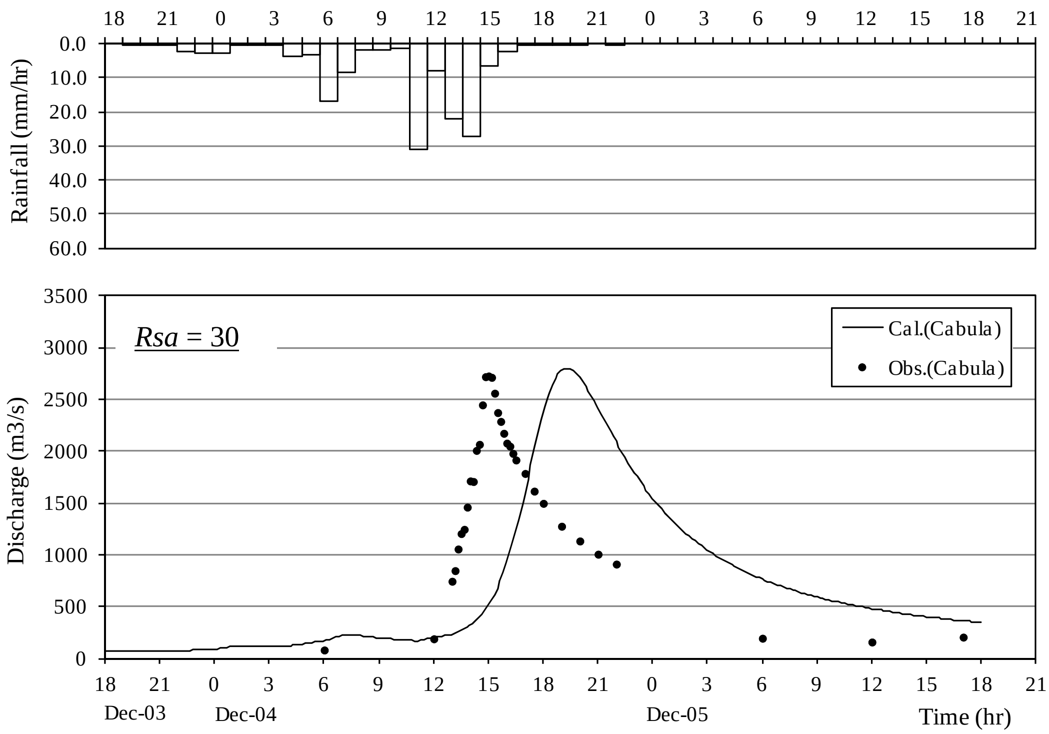
Source: JICA Survey Team

Figure 4.3.1 Location of Rainfall Stations with Available Hourly Rainfall Record and Thiessen Pattern of Those Stations



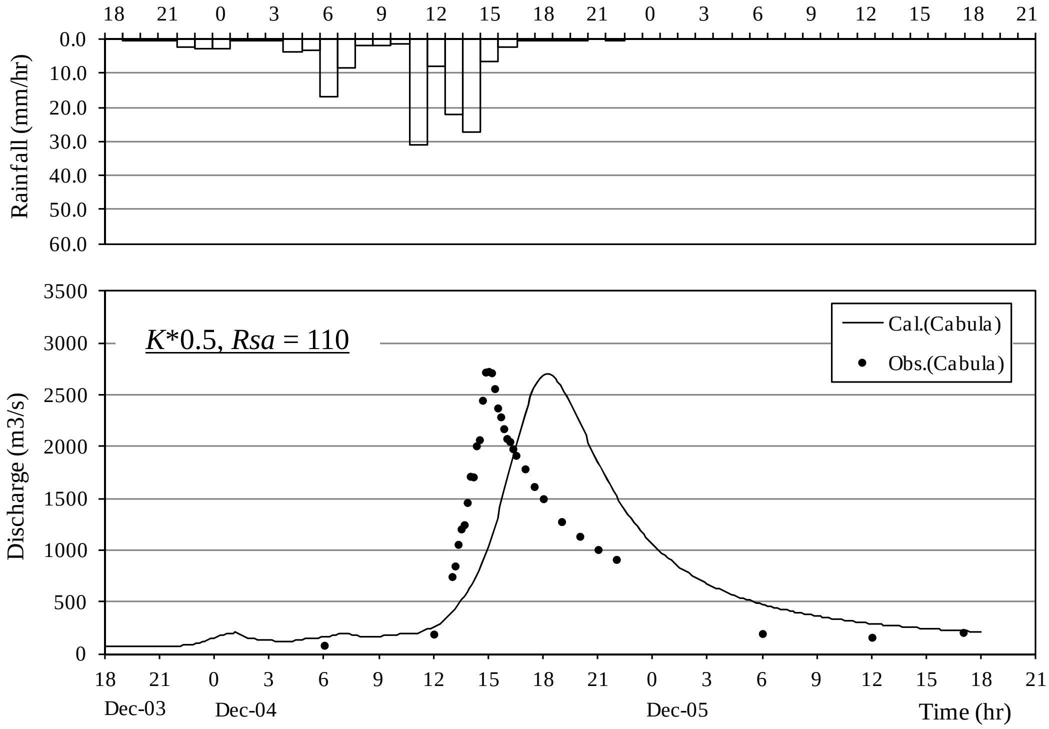
Source: JICA Survey Team

Figure 4.3.2 Observed Hourly Rainfall Record in TY Pablo



Source: JICA Survey Team

Figure 4.3.3 Comparison of Hydrograph of Simulated by Runoff Model(First estimate parameter) and Hydrograph in Pablo based on the Observed Record



Source: JICA Survey Team

Figure 4.3.4 Comparison of Hydrograph of Simulated by Runoff Model (2nd estimate parameter) and Hydrograph in Pablo based on the Observed Record

Even after adjustment of K and Rsa values, discharge ascending of the hydrograph by the runoff model is not rapid yet and shape of the hydrograph is not as sharp as the discharge hydrograph based on the observation data.

2) Parameter adjustment

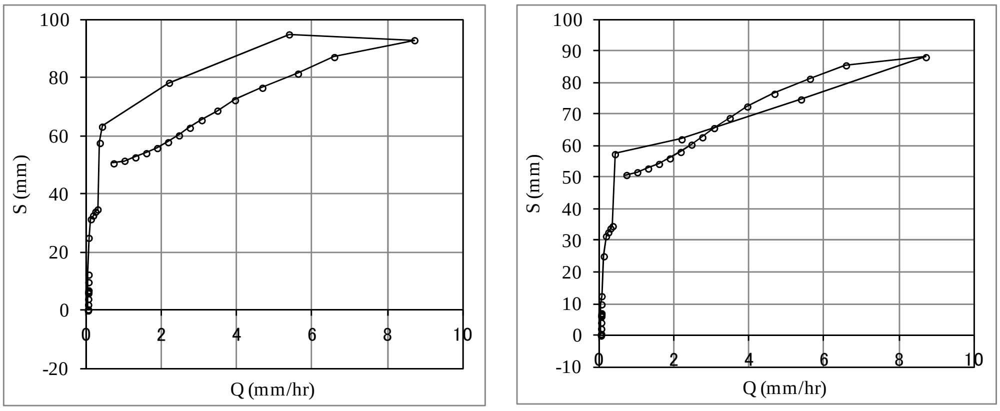
Parameter adjustment was made in such way that the relation between basin storage and runoff(S-Q relation) was worked out assuming one(1) catchment at the Cabula Bridge.

The basin storage height(S) is defined as follows:

$$S = \sum \left\{ r_{ave} - \frac{3.6}{A}\left(Q - Q_b\right) \right\} \cdot \Delta t$$

where,
- S : Basin storage height(mm)
- r_{ave} : Basin mean rainfall(mm/hr)
- Q : Discharge (m^3/s)
- Q_b : Base flow (m^3/s)
- A : Catchment area (km^2)

S-Q relations at T_l =0 and T_l =1 are shown in Figure 4.3.5



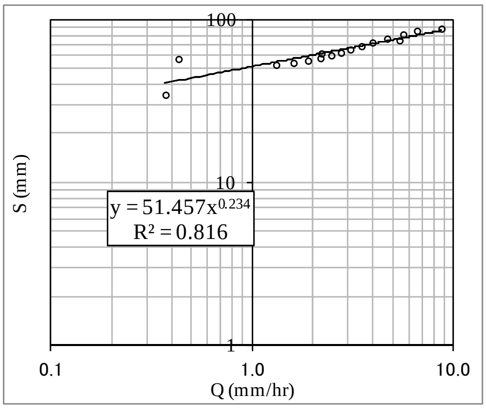
(1) T_l = 0 hr (2) T_l = 1 hr

Source: JICA Survey Team

Figure 4.3.5 Relationship between Basin Storage Height and Runoff Height in TY.Pablo

In the Storage Function method, the S-Q relation is defined as the single valued exponential of $S = KQ^p$. In case of T_l =0, the S-Q relation is not expressed as the single valued function as shown in Figure 4.3.5 (1). While, the S-Q relation can be optimized as the single valued function (minimized loop) when T_l =1, and then it was evaluated that basin delay of time is to be at 1.0 hour.

The S-Q relation is plotted on the logarithmic graph as shown in Figure 4.3.6.



Source: JICA Survey Team

Figure 4.3.6 Relationship between Storage and Runoff in Pablo Flood

Table 4.3.2 presents summary of the optimum parameters of sub-basins of the Storage Function runoff model representing runoff phenomena in CDO River Basin.

Rsa is evaluated to be 120mm and examined by using the following three methods.

i) Calculating Rsa by assumption of initial runoff coefficient (f1)
ii) Using mass curve
iii) Using rating curve between total rainfall and total runoff occurred in the past

Table 4.3.2 Optimum Parameters of Sub-basins in CDO River Basin

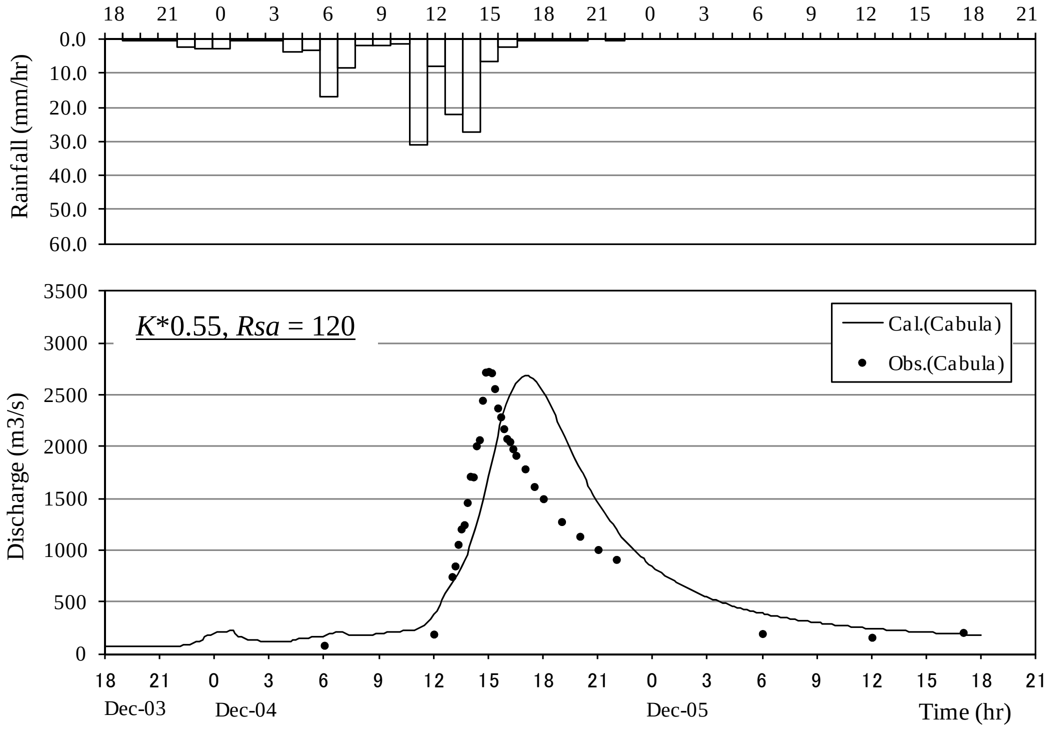
№	Sub-basin	Basin Area (km2)	K	P	TL	f1
1	1Bulanog-1	90.0	25.5	0.230	0.3	0.5
2	2Bulanog-2	72.5	27.2	0.230	0.3	0.5
3	3Sangaya-1	97.6	18.0	0.230	0.2	0.5
4	4Sangaya-2	78.6	20.7	0.230	0.3	0.5
5	5Batang-1	55.2	17.3	0.230	0.2	0.5
6	6Batang-2	57.5	29.4	0.230	0.5	0.5
7	7Pikalin	72.4	28.3	0.230	0.8	0.5
8	8Bulanog-3	93.7	25.9	0.230	0.4	0.5
9	9Tulohan	114.4	27.6	0.230	0.6	0.5
10	10Kalawaig	80.6	27.7	0.230	0.7	0.5
11	11Tagite	46.5	25.6	0.230	0.5	0.5
12	12Mamala	38.5	30.4	0.230	0.4	0.5
13	13Cagayan-1	66.7	18.2	0.230	0.1	0.5
14	14Samalauan	47.8	17.5	0.230	0.2	0.5
15	15Lumalaong	82.1	29.6	0.230	0.5	0.5
16	16Bubunauan-1	99.7	18.5	0.230	0.3	0.5
17	17Bubunauan-2	86.6	24.6	0.230	0.2	0.5
18	18Bubunauan-3	37.1	30.6	0.230	0.3	0.5
19	19Cagayan-2	46.6	17.8	0.230	0.1	0.5

Source: JICA Survey Team

4) Flood runoff hydrograph of TY. Pablo

The simulated flood runoff hydrograph in TY Pablo is shown in Figure 4.3.7 by applying the optimum parameters of sub-basins of the runoff model shown in Table 4.3.2. The input rainfall is same as those shown in Figure 4.3.3.

Comparing to the flood hydrograph based on the observed data in TY Pablo, the hydrograph by the runoff model showed good conformity with the rising limb of the hydrograph and peak discharge, however, the hydrograph still contained low recession ratio. The runoff coefficient of the simulated hydrograph would be lower than 0.5 in case that simulated hydrograph would be forced to be similar to the "observed" hydrograph.



Source: JICA Survey Team

Figure 4.3.7 Calibrated Discharge Hydrograph at Cabula Bridge after Parameter Adjustment (Adjustment of time of delay)

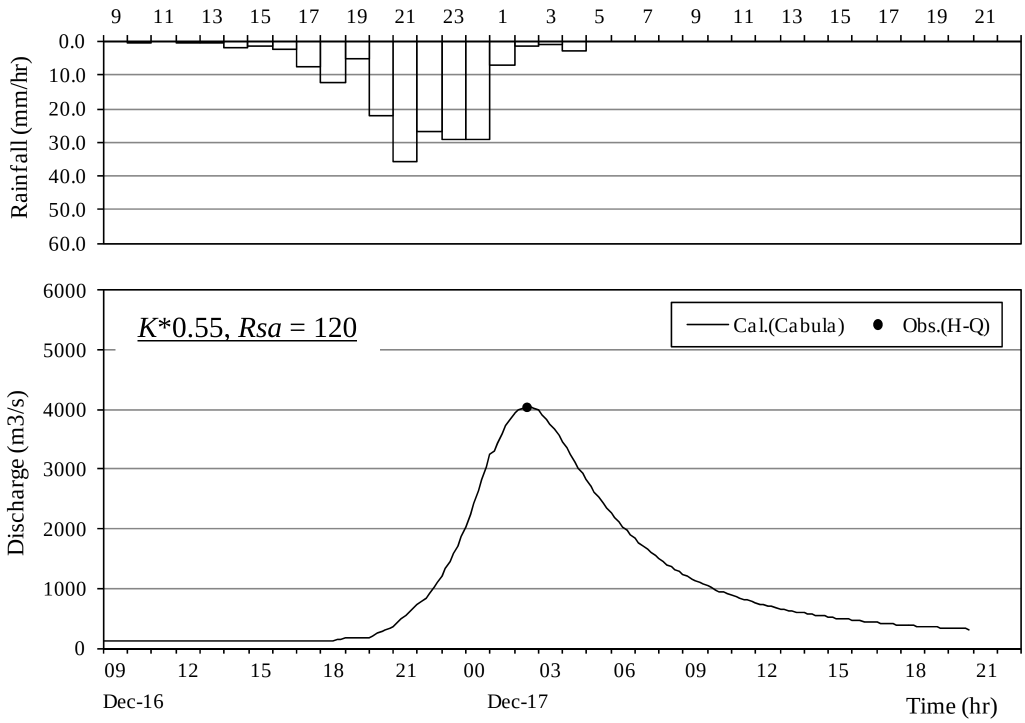
(2) Verification of Peak Discharge at Cabula Bridge during TS. Sendong

1) Flood runoff hydrograph at Cabula Bridge in TS. Sendong

As described in 4.2, the highest gauge reading height was 9.8 m at the Cabula Bridge during TS. Sendong, which is equivalent to the peak discharge at about 4,050 m^3/s by applying the water level – discharge rating curve shown in Figure 4.2.3.

The base flow is around $100m^3/s$ ($0.1m^3/s/km^2$) on day 15^{th} and 16^{th} days of December according to daily observed water level in Appendix P in DATA BOOK.

The flood hydrograph having been calibrated by the observed data in TY Pablo with a peak discharge is shown in Figure 4.3.7.



Source: JICA Survey Team

Figure 4.3.7 Flood runoff hydrograph at Cabula Bridge in TS. Sendong

2) Assessment of the peak discharge by applying Rational formula

The Rational formula as defined below was used for estimation of high flow by determining the parameters below:

$$Qp = 1/3.6 \times f \times R \times A$$

where,

Qp : Peak runoff (m^3/s)

f : Runoff coefficient

R : Rainfall intensity during flood travelling time (mm/hr)

A : Catchment area (km^2)

a) Time of flood concentration was estimated by applying Kraven Formula which gives flood wave propagation time:

Slope	> 1/100	1/100 ~ 1/200	< 1/200
Velocity	3.5 m/s	3.0 m/s	2.1 m/s

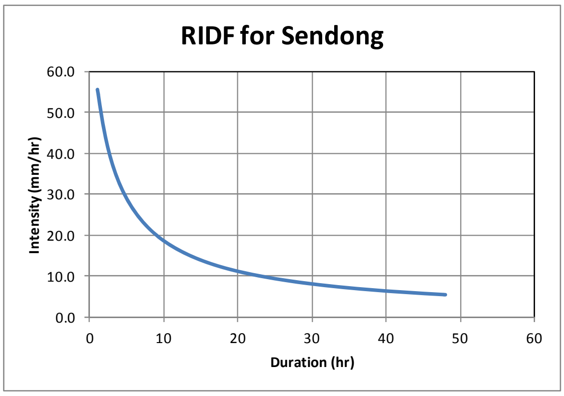
Time of flood concentration time from the most far sub-basin(s) are shown as follows:

No.	Sub-Basin	Length L (km)	High EL. (m)	Low EL. (m)	Diff (m)	1/Slope	Velocity (m/s)	Flow time (hr)
3	Sangaya-1	19.5	2400	920	1480	13.2	3.5	1.5
4	Sangaya-2	22.8	1900	650	1250	18.3	3.5	1.8
6	Batang-2	21.0	650	380	270	77.9	3.5	1.7
13	Cagayan de Oro-1	17.9	140	50	90	198.8	3	1.7

Consequently, total flood concentration time to the Cabula Bridge was estimated at 7 hours.

b) Rainfall intensity

Referring to the hourly rainfall data available at Talakag during TS. Sendong, Rainfall Intensity Duration Frequency(RIDF) was prepared:



Source: JICA Survey Team

According to the figure above, 7-hr rainfall intensity was obtained at 23.5 mm/hr.

c) Runoff coefficient

Runoff coefficient in undulating highland or forest is in a range of 0.50 to 0.70 according to the "Manual for River Works in Japan". Qp was computed at about 3,570 m^3/s (coeff. 0.5) and 4,280 m^3/s (coeff. 0.60), respectively. A coefficient of 0.57 corresponds to a peak discharge of the current hydrograph (Q= 4,050m^3/s).

CHAPTER 5 PROBABLE FLOOD HYDROGRAPH

5.1 Runoff Parameter

Optimum parameters to be applied for determination of the probable flood hydrograph are specified in Table 4.1.2 for *K*, *P* and T_l of each river channel and in Table 4.3.2 for the area, f_1, *K*, *P* and T_l of each sub-basin.

As for an amount of the saturated rainfall depth(Rsa) , it is determined to employ Rsa of 120 mm.

5.2 Flood Hydrographs during TS. Sendong at the Selected Locations on the Cagayan de Oro River

Discharge hydrographs at the selected locations in the Cagayan de Oro River during TS. Sendong were obtained in the following manner:

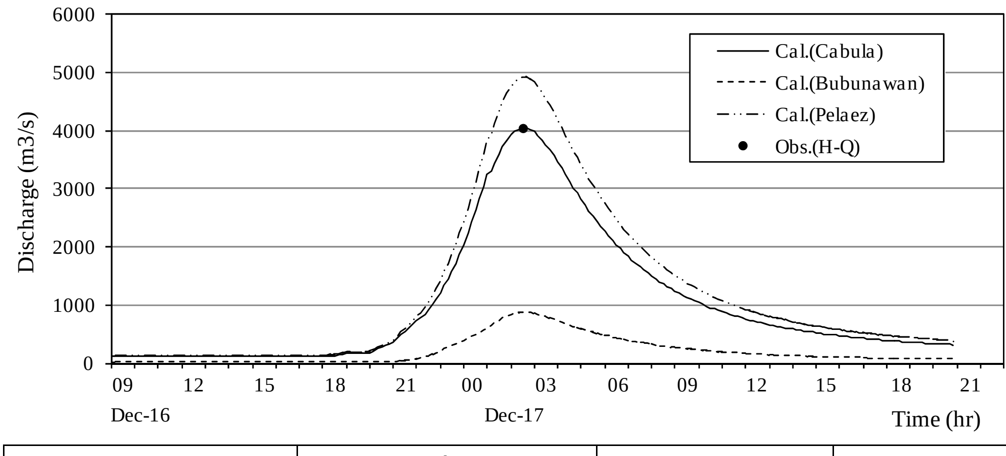
(1) Bubunawan : Flood hydrograph obtained by runoff model in the Bubunawan River sub-basins which directly flow into the river runoff model at the confluence.

(2) Cabula Bridge : Flood hydrograph obtained through the Runoff Model; Inflow from Bubunawan River sub-basins and Cagayan de Oro-2 sub-basin are not included.

(3) Pelaez Bridge : Flood hydrograph through the Runoff Model; Inflow from Cagayan de Oro- 2 sub-basin is not included.

(4) Kausuwagan Bridge : Flood hydrograph through the Runoff Model; Inflow from Cagayan de Oro- 2 sub-basin is included. This would be the input flow for hydraulic analysis in next Chapter.

The each location of (1), (2), and (3) is described in Figure 1.2.1 and Figure 2.4.1.



Name of Basin	Distance from River Mouth(km)	Catchment Area (km^2)	Sendong Flow (m^3/s)
Cabula	18.7	1,094	4,052
Pelaez	11.62	1,317	4,925
Bubunawan Basin	-	223	872

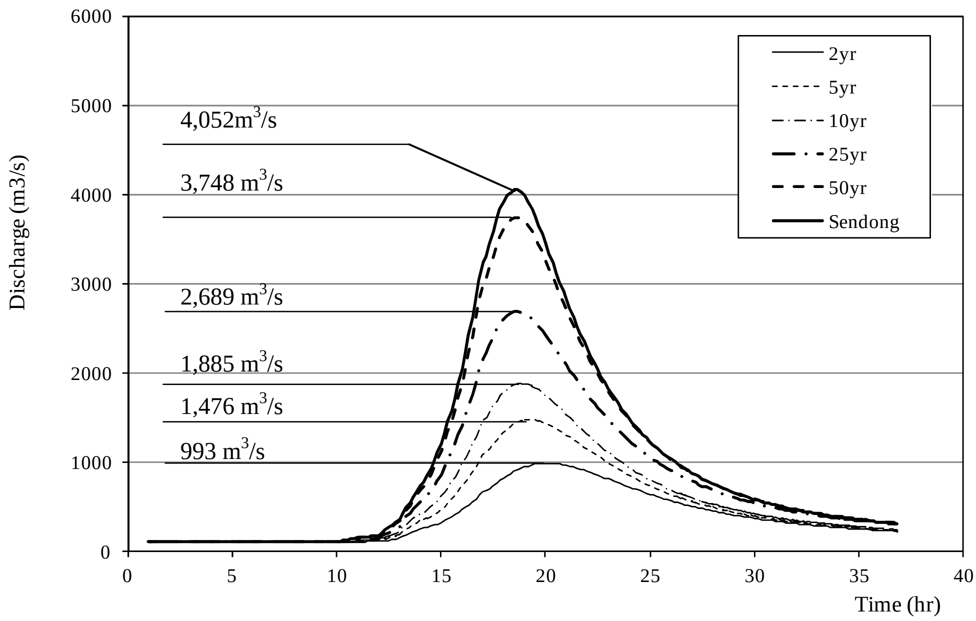
Source: JICA Survey Team

Figure 5.2.1 Discharge Hydrographs during Sendong (Cabula Bridge)

5.3 Selected Discharge Hydrographs for Design Scale Alternatives

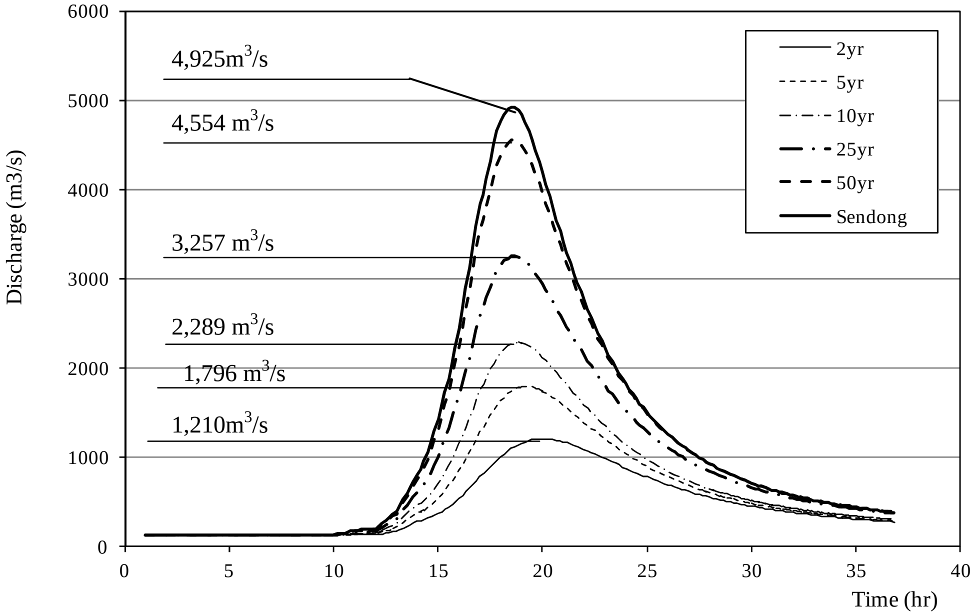
Selected discharge hydrograph for the design scale alternatives at the selected locations are presented herein for the Cabula Bridge and the Pelaez Bridge in Figures 5.3.1 and 5.3.2, respectively with probable flood of 2-yr, 5-yr, 10-yr, 25-yr and 50-yr as well as Sendong-yr return period.

Return Period	Flood Discharge (m^3/s) at Cabula Bridge	Flood Discharge (m^3/s) at Pelaez Bridge	Flood Discharge (m^3/s) at Kausuwagan Bridge
2 year	1,000	1,300	1,300
5 year	1,500	1,800	1,900
10 year	1,900	2,300	2,400
25 year	2,700	3,300	3,400
50 year	3,800	4,600	4,700
TS.Sendong Scale	4,100	5,000	5,100



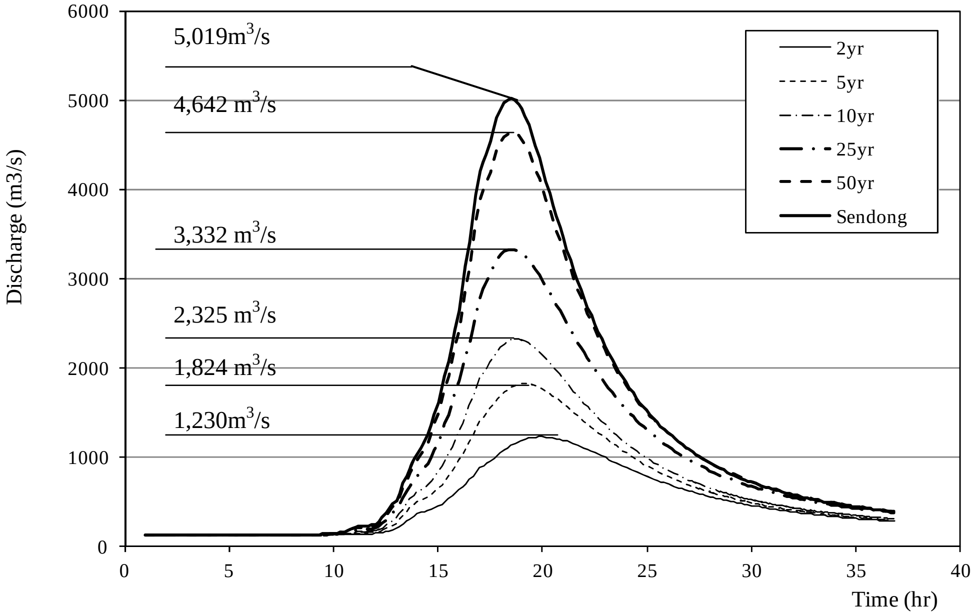
Source: JICA Survey Team

Figure 5.3.1 Flood Hydrographs at Cabula Bridge



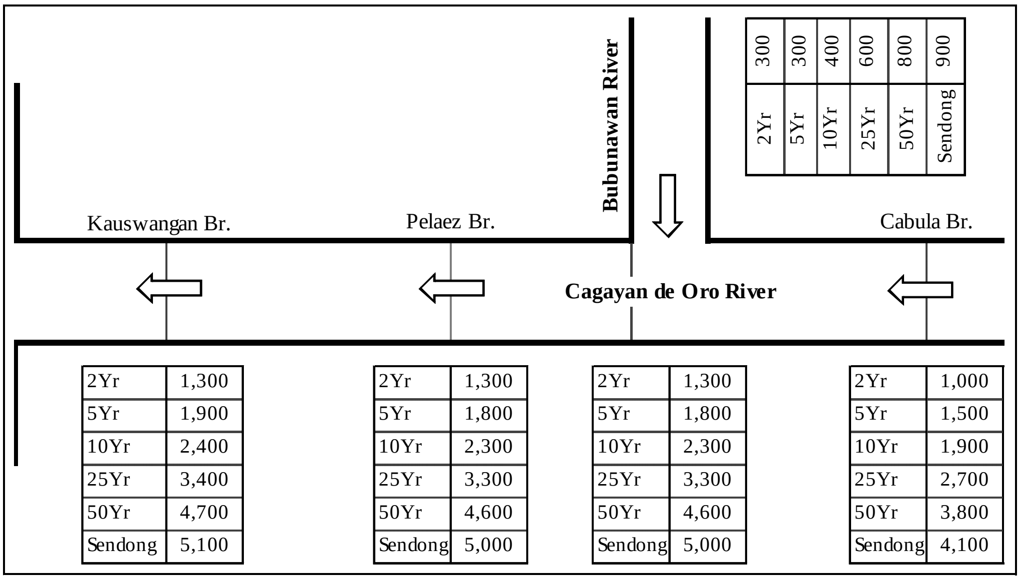
Source: JICA Survey Team

Figure 5.3.2 Flood Hydrographs at Pelaez Bridge



Source: JICA Survey Team

Figure 5.3.3 Flood Hydrographs at Kausuwagan Bridge



Source: JICA Survey Team

Figure 5.3.4 Flood Discharge Distribution (Return Period and Sendong Flood)

5.4 Flood Hydrograph at the Proposed Dam Site

As shown in Figure 5.4.1, proposed dam site is located at the boundary of Bulanog and Batang tributary.

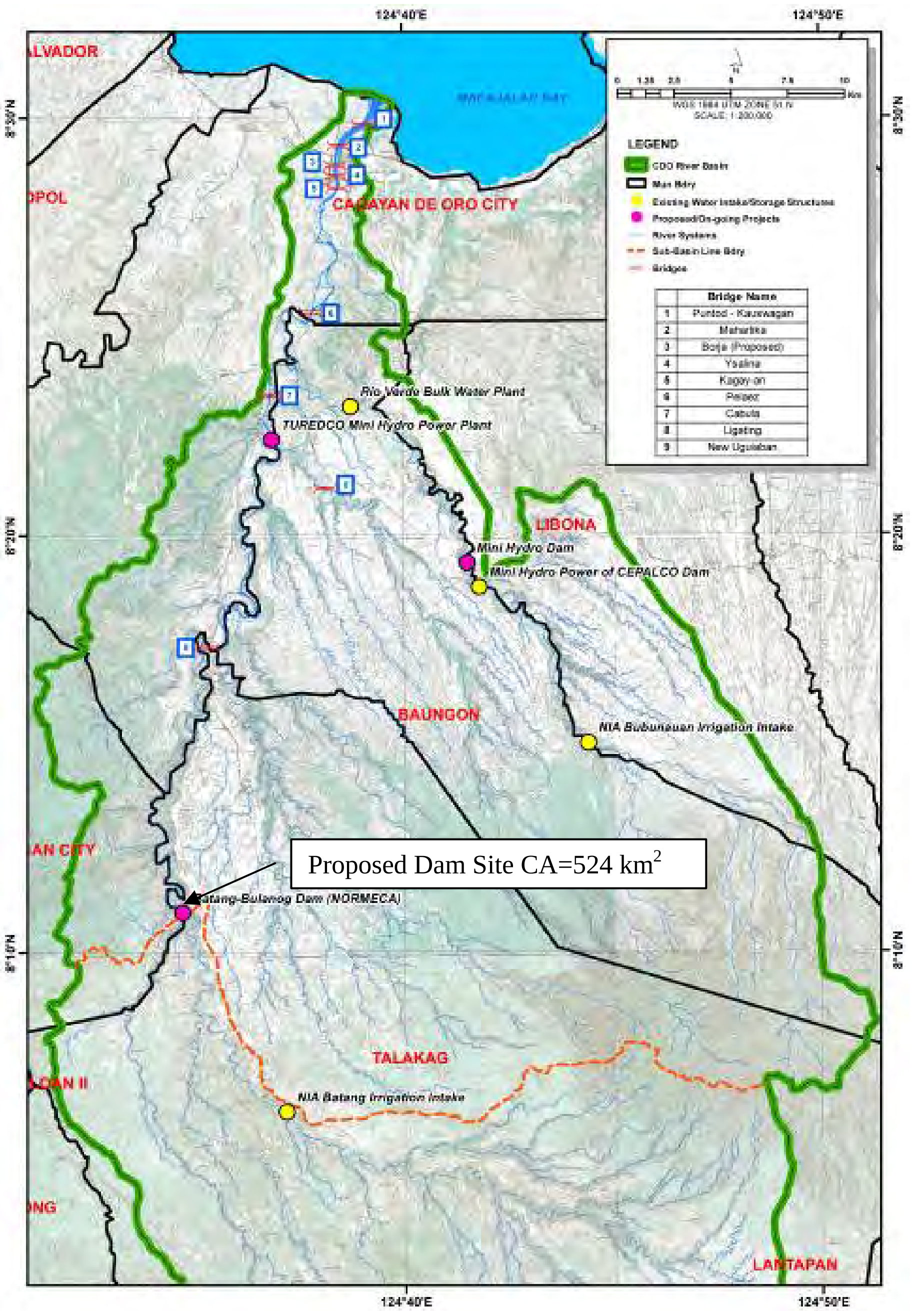
(1) River Basin Area and Model Condition

In terms of runoff model, the upstream of the proposed dam site is divided into 7 sub-basins as shown below, which is the same sub-basin shown in Figure 4.1.2.

№	Sub-Basin	Basin Area (km2)
1	1Bulanog-1	90.0
2	2Bulanog-2	72.5
3	3Sangaya-1	97.6
4	4Sangaya-2	78.6
5	5Batang-1	55.2
6	6Batang-2	57.5
7	7Pikalin	72.4
Total		523.8

Source: JICA Survey Team

Probable rainfall for input to runoff model and model parameters are the same as previous sections, which are shown in Figure 3.4.6 and Table 4.3.2, respectively.

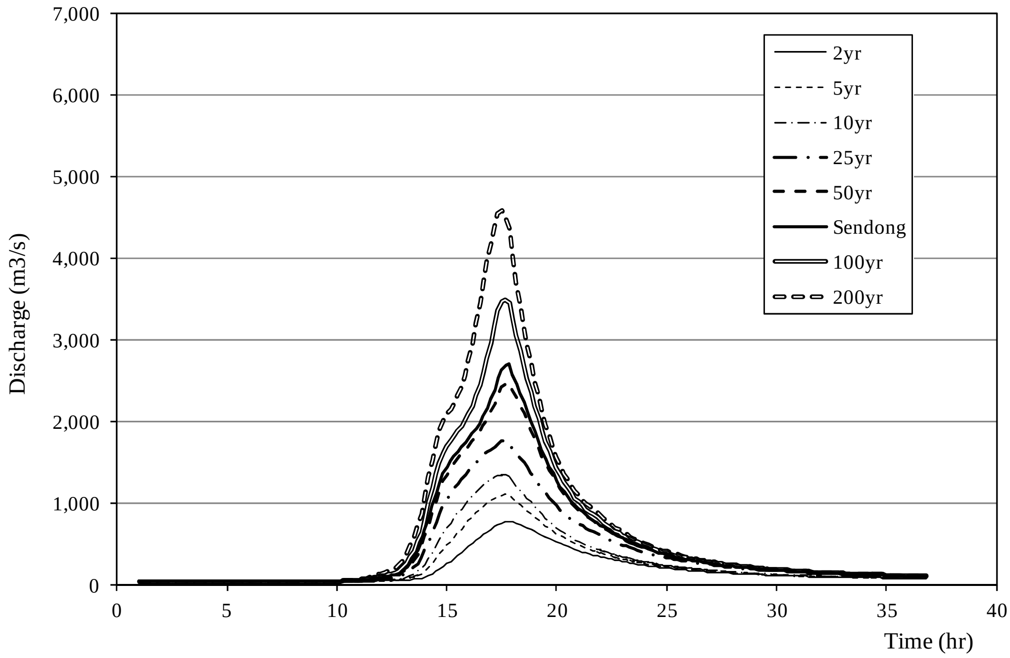


Source: JICA Survey Team

Figure 5.4.1 Proposed Dam Site

(2) Flood Hydrograph at the Proposed Dam Site

The flood inflow hydrograph at the proposed dam site is shown in Figure 5.4.2. Inflow discharge for 25-year return period is 1,768 m^3/s and 4,549 m^3/s for 200 years return period ..



Source: JICA Survey Team

Figure 5.4.2 Hydrograph at the Proposed Dam Site

Chapter 6 HYDRAULIC ANALYSIS

6.1 Past Inundation

In Cagayan de Oro River Basin, the floods caused by Tropical Storm Sendong in 2011 and Typhoon Pablo in 2012 wreaked enormous damage. The overall condition of TS Sendong and TY Pablo are described hereinafter.

6.1.1 TS Sendong

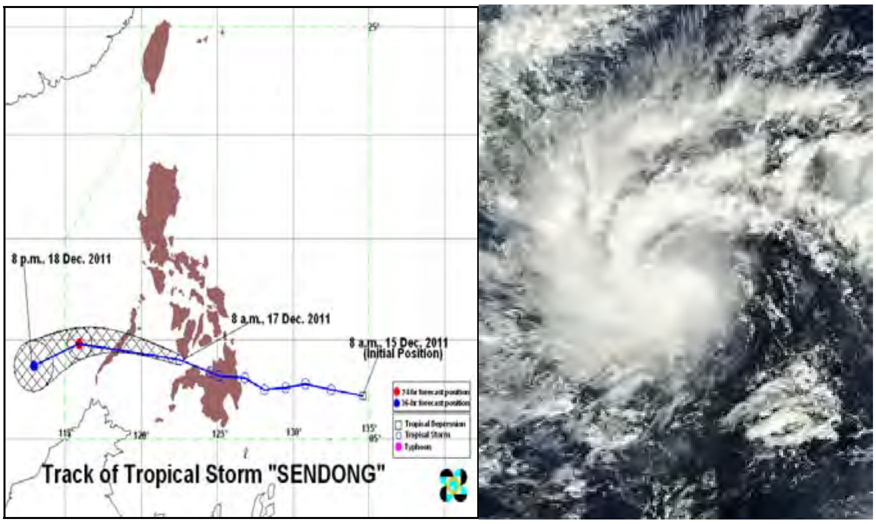
(1) General

TS Sendong (International Name: Tropical Storm Washi) occurred in Philippine Sea 13th December, 2011 and entered into PAR at 8AM on 15th December. It made landfall in Mindanao Island at 2PM on the 16th with recorded 992 hpa for central pressure, 95 km/h for maximum instantaneous wind speed. It had continuously rained at Talakag rainfall Station whose maximum rainfall per hour is 60.5mm and total rainfall is 230.5mm since 2PM on the 16th to 4AM on the 17th, for 15 hours, in Cagayan de Oro River Basin. There are 1,206 dead and 52,435 damaged houses in Region X including Cagayan de Oro River Basin. Table 6.1.1 shows the record of damage and Figure 6.1.1 shows track and satellite image of TS Sendong.

Table 6.1.1 Damage in Cagayan de Oro River Basin by TS Sendong

	Affected and/or Displaced				Damaged Houses
	Persons	Dead	Injured	Missing	Totally/Partially
All	1,168,726	1,268	6,071	181	14,883/37,552
Region-X	342,400	1,206	-	-	211,463/28,095

Source: NDRRMC, SITREP No.47, Jan. 2012

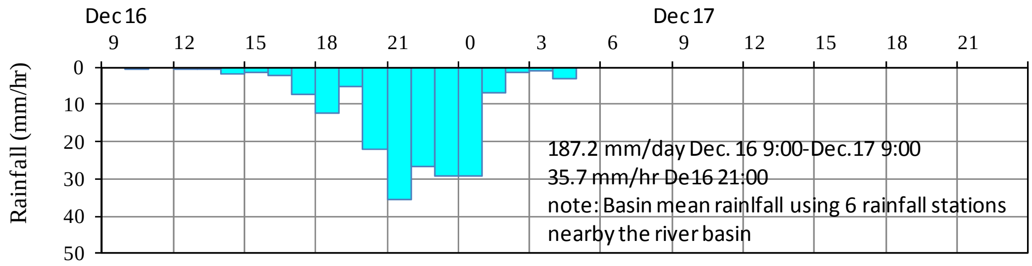


Source: National Institute of Information

Figure 6.1.1 Track (Left) and Satellite Image (Right) of Sendong

(2) Basin Mean Rainfall

Basin mean rainfall of TS Sendong calculated by Theissen method using 6 rainfall stations near by the river basin shows that the peak rainfall is 187.2mm 24hour rainfall and 35.7mm 1 hour rainfall. The one day rainfall is about 50years return period by probability evaluation. Table 6.1.2 shows the hyetograph.



Source: JICA Survey Team

Figure 6.1.2 Basin Mean Rainfall (TS Sendong)

(3) Water Level and Flood Discharge

Though there are no record of Water Level and Discharge during TS Sendong, the flood mark was observed at Cabula Bridge.

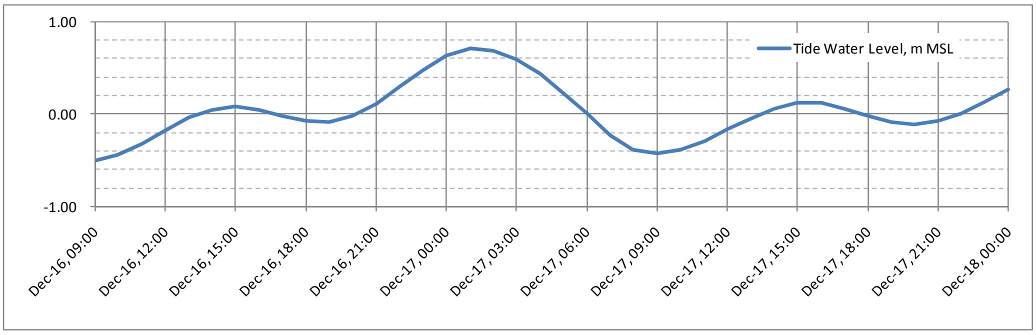
Table 6.1.2 Water Level and Discharge at Cabula Bridge (TS Sendong)

Class	Observed Value	Remarks
Flood Mark	9.8 m	Gauge Height
Discharge	4,050 m^3/s	$Q=170.4(h - 1.5)^{1.5}$

Source: JICA Survey Team

(4) Tide Level

The tide level has been observed at Macabalan Port near by Cagaya de Oro River mouth. Figure 6.1.3 shows the tide graph.



Source: NAMRIA

Figure 6.1.3 Tide of Macabalan Port (TS Sendong)

(5) Flood Marks

JICA Survey Team has conducted survey of flood marks at each bridge from river mouth up to Pelaez bridge. JICA also conducted the survey for upstream from Pelaez bridge and at Kauswagan Bridge, Maharlika Bridge and Ysalina Bridge with construction of new bridge.

Table 6.1.3 Flood Mark Elevation (TS Sendong)

Name of Survey	Investigation Point	Station	Flood Mark	Remarks
This Survey[*1]	Kauswagan Br.	1+504	4.14m	Datum: Macajalar Bay mean sea level
	Maharika Br.	2+927	4.86m	
	Ysalina Br.	4+299	7.19m	
JICA, Woodfield Consultants Inc.[*2]	Pelaez Br.	11+606	18.57 m	Datum: Temporary Bench Mark
	Section 1	11+718	19.83m	
	Section 2	12+101	20.28m	
	Section 3	12+453	21.23m	
	Section 4	12+765	24.48m	
	Section 5	13+082	26.60m	
	Section 6	13+386	26.75m	
	Section 7	13+581	26.74m	
	Section 7-A	13+716	27.06m	
	Section 8	13+801	26.75m	
	Section 9	14+048	26.77m	
	Section 10	14+388	30.54m	
	Section 11	14+573	30.54m	
	Section 12	14+838	30.60m	
	Section 12-A	15+009	33.81m	
	Section 13	15+098	30.60m	
	Section 14	15+276	34.14m	
	Section 15	15+479	34.56m	
	Section 16	15+786	34.56m	
	Section 17	15+975	34.64m	
	Section 18	16+140	34.65m	
	Section 19	16+279	35.79m	
DPWH, CENTUNION Philippines, Inc.	Kauswagan Br.	1+504	1.5-2.0m below the beam	
	Maharika Br	2+927	2.0-2.5m below the beam	
	Ysalina Br.	4+299	Reach the beam	

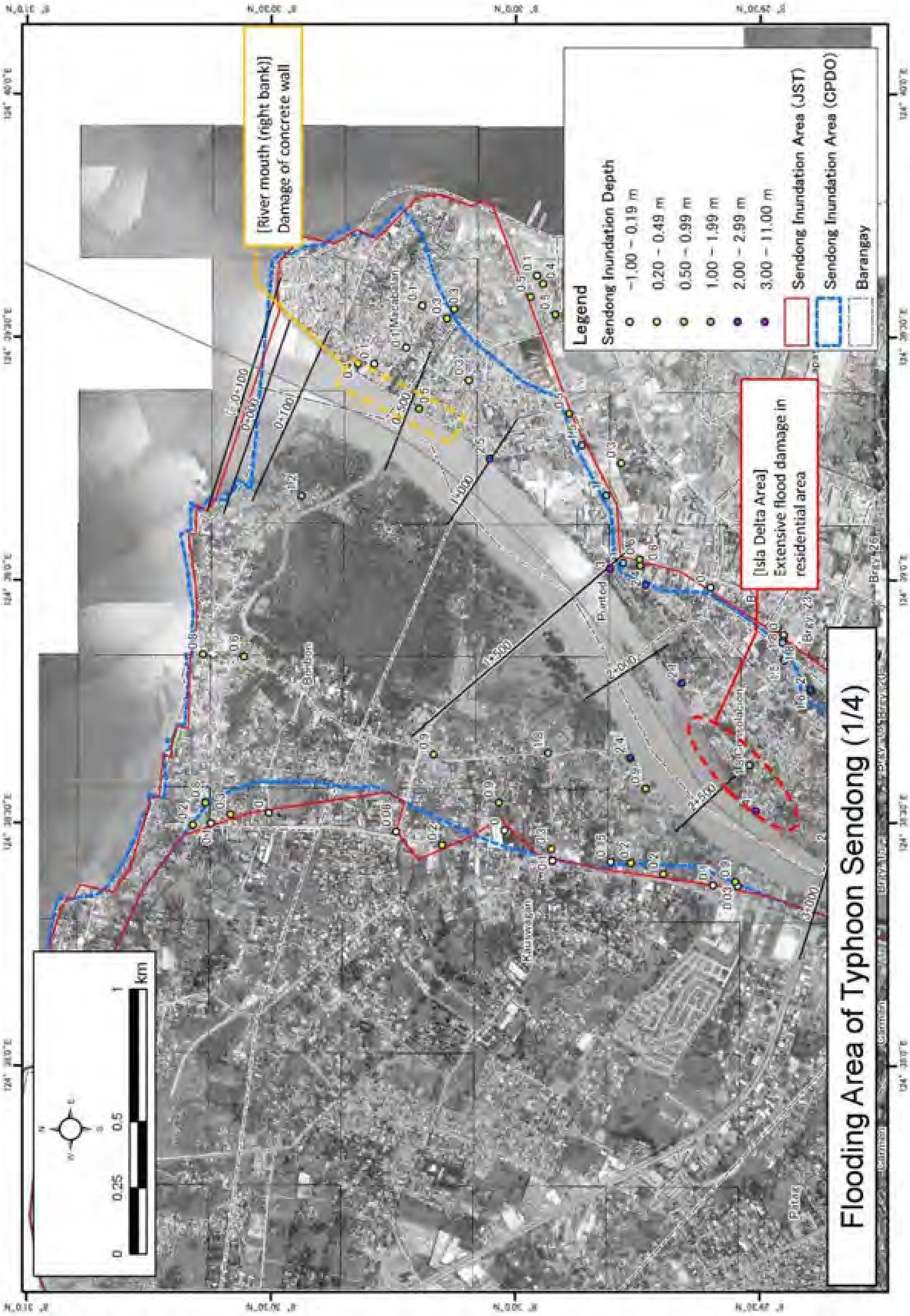
Source: 1) JICA Survey Team
2) Flood Condition Survey of Tropical Storm "Sendong" in Cagayan de Oro and Iligan City (JICA, March 2012)

(6) Condition of Inundation Depth, Area of Inundation and Flood Damage

JICA survey team has conducted the survey of inundation depth of TS Sendong taking around 200 points depth. Also, the City Planning and Development Office in CDO City summarized the area of inundation. The survey team modified the area according to JICA inundation survey and the geography of the river basin, and put the damage situation with the actual interview at the site. Figure 6.1.4 shows the condition of inundation depth, area of the inundated and damage situation.

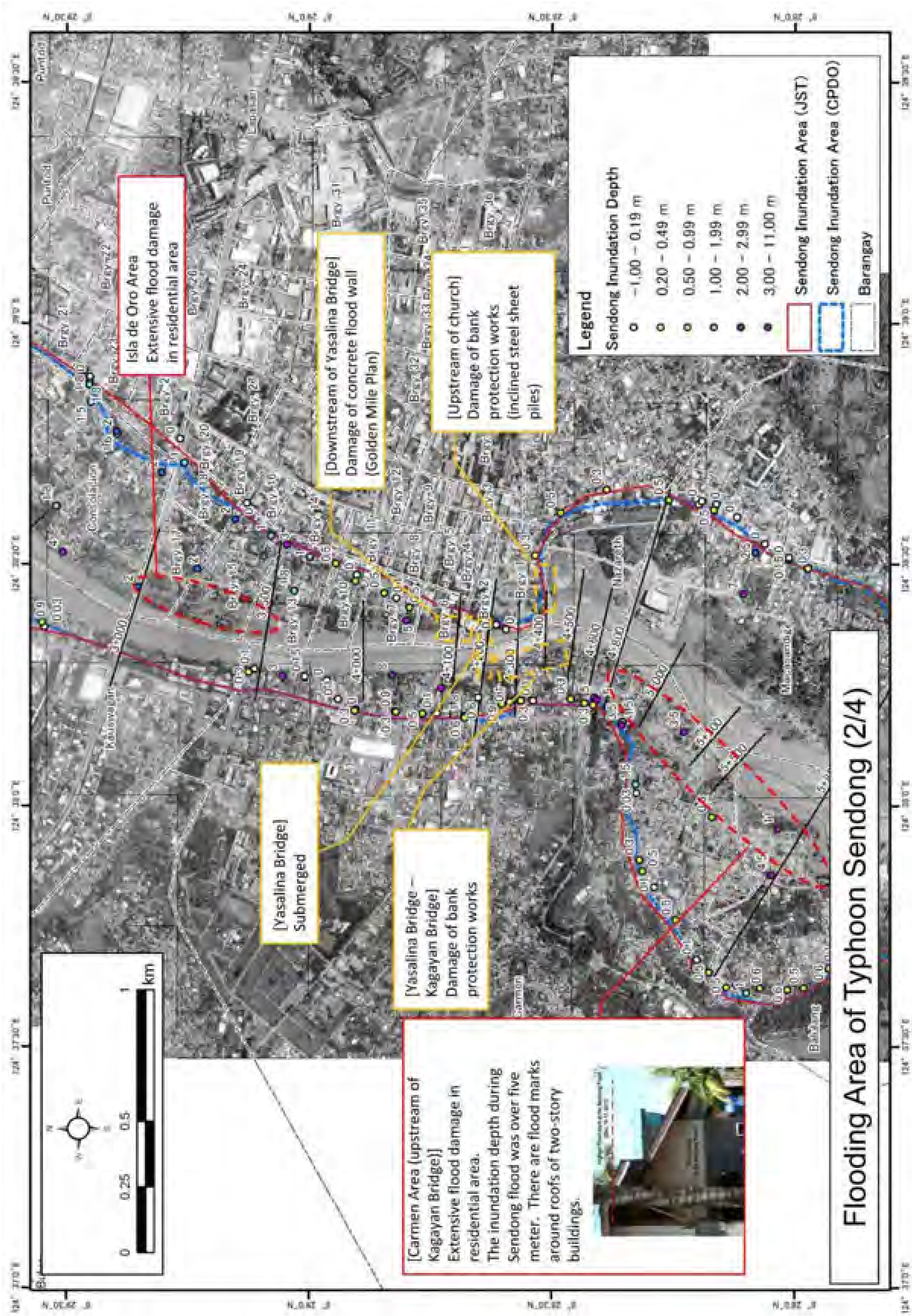
(7) Change of River Channel

This survey provided cross section leveling in 2012, as well as the other agency did in 2011. It has done to compare both of said cross section to get the change of river channel in Appendix A.



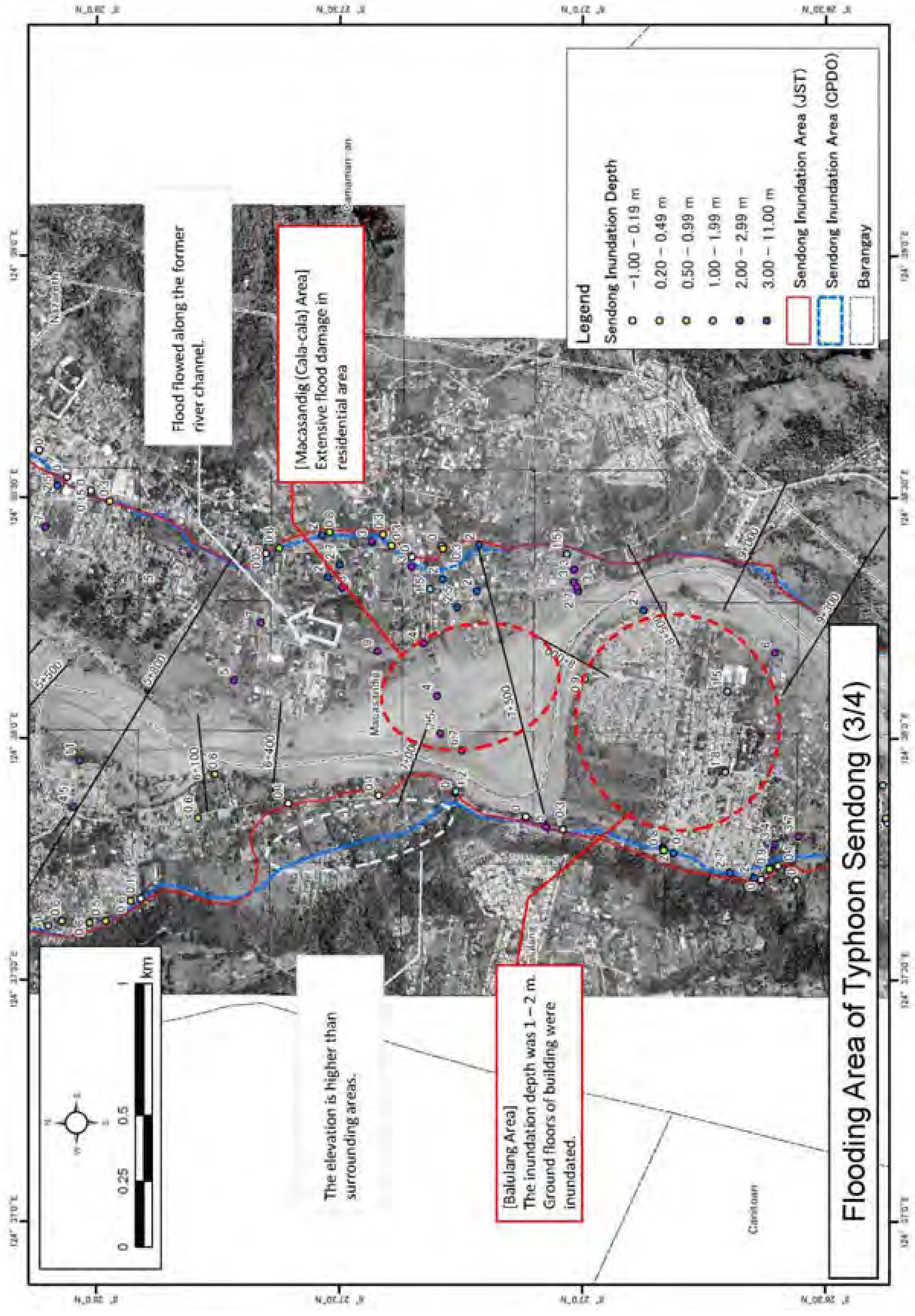
Source: JICA Survey Team

Figure 6.1.4 Inundation Depth, Area of Inundated and Flood Damage of TS Sendong (1/4)



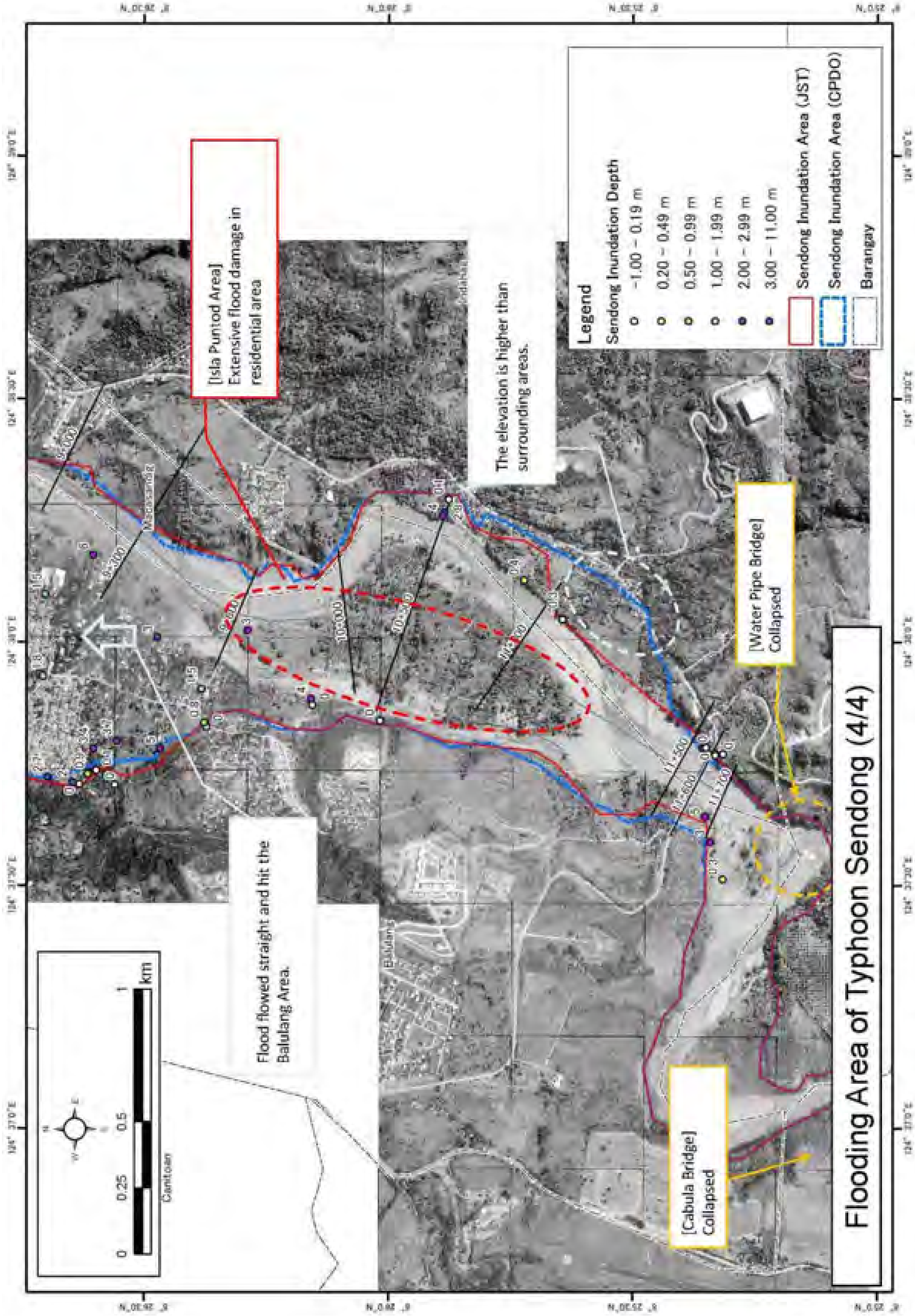
Source: JICA Survey Team

Figure 6.1.4 Inundation Depth, Area of Inundated and Flood Damage of TS Sendong (2/4)



Source: JICA Survey Team

Figure 6.1.4 Inundation Depth, Area of Inundated and Flood Damage of TS Sendong (3/4)



Source: JICA Survey Team

Figure 6.1.4 Inundation Depth, Area of Inundated and Flood Damage of TS Sendong (4/4)

6.1.2 Typhoon Pablo

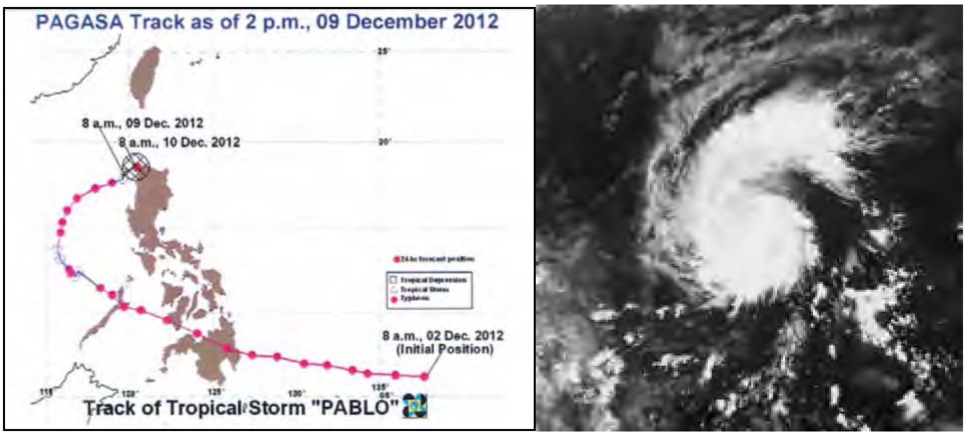
1) General

TY Pablo (International Name: Typhoon Bopha) occurred in Philippines Sea on the 26th November, 2012, entering the PAR at 8AM in 2nd December. It made landfall in Mindanao at 5AM on 4th, and recorded 930 hpa of central pressure, 185 km/h for maximum instantaneous wind speed. The wind speed is faster than TS Sendong and caused the serious wind damage. It had continuously rained at Talakag rainfall Station with maximum rainfall per hour is 39.5mm and total rainfall is 155.0mm since 4AM to 17PM in 4th, for 14 hours, in Cagayan de Oro River Basin. There are, totally 1,067 dead and 216,817 damaged houses. On the other hand, in Region X including Cagayan de Oro River Basin, there are 15 dead and injured. Table 6.1.4 shows the record of damage and Figure 6.1.5 shows track and satellite image of TY Pablo.

Table 6.1.4 Damage in Whole Area and Region X by TY Pablo

	Affected and/or Displaced				Damaged Houses
	Persons	Dead	Injured	Missing	Totally/Partially
All	6,243,998	1,067	2,666	834	89,666/127,151
Region-X	523,194	15	-	-	1,775/11.127

Source: NDRRMC, SITREP No.38 Dec.25, 2012

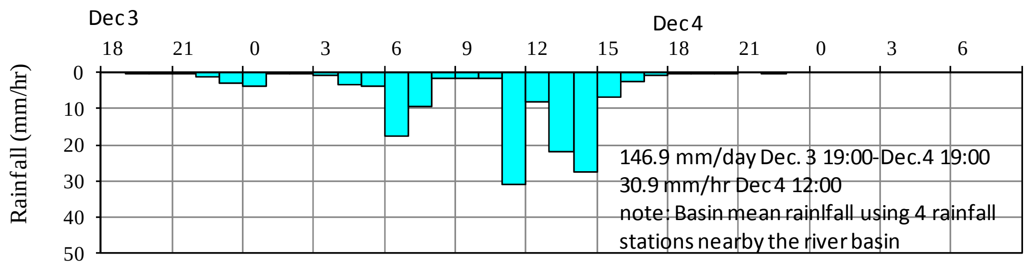


Source: National Institute of Information

Figure 6.1.5 Track (Left) and Satellite Image (Right) of TY Pablo

2) Basin Mean Rainfall

Basin mean rainfall of TY Pablo calculated by Theissen method using 4 rainfall stations near by the river basin shows that the peak rainfall is 146.9mm 24hour rainfall and 30.9mm 1 hour rainfall. The one day rainfall is about 15years return period by probability evaluation. Table 6.1.6 shows the hyetograph.

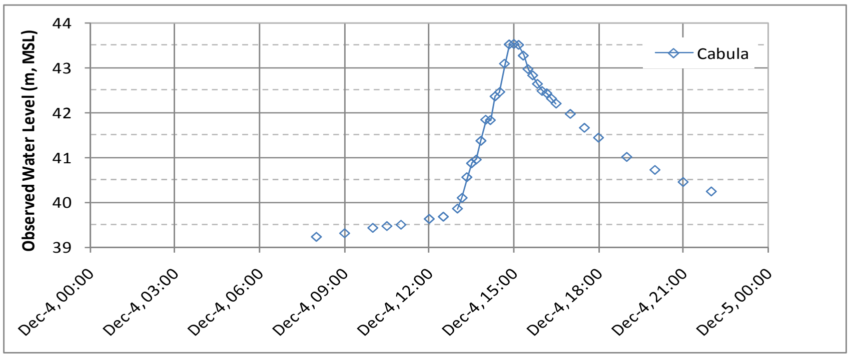


Source: JICA Survey Team

Figure 6.1.6 Basin Mean Rainfall

(3) Water Level and Flood Discharge

Figure 6.1.7 shows the hydrograph of water level at the Cabula bridge during TY Pablo and Table 6.1.5 shows the peak water level and peak discharge.



Datum: Macajalar Bay mean sea level

Source: Project NOAH

Figure 6.1.7 Observed Water Level (TY Pablo)

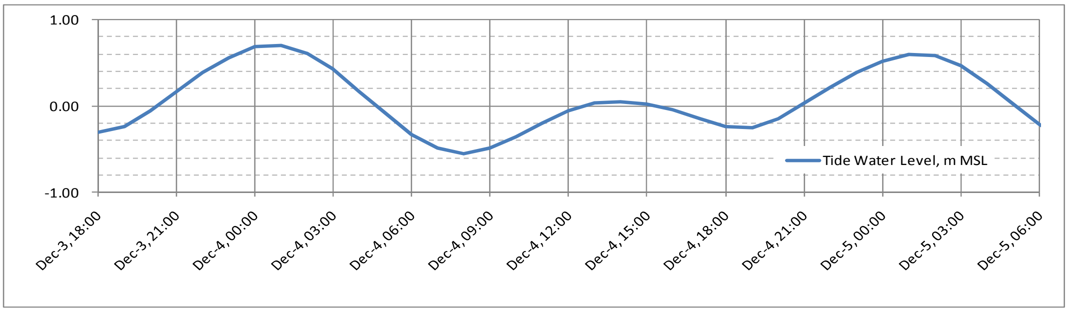
Table 6.1.5 Peak Water Level and Discharge at Cabula Bridge (TY Pablo)

Class	Observed Value	Remarks
Water Level	7.8m	Project NOAH
Discharge	2,708m^3/s	$Q=170.4(h - 1.5)^{1.5}$

Source: JICA Survey Team

(4) Tide Level

The tide level has been observed at Macabalan Port nearby Cagaya de Oro Rive mouth. Figure 6.1.8 shows the tide graph.



Source: NAMRIA

Figure 6.1.8 The Tide of Macabalan Port (TY Pablo)

(5) Flood Mark

The survey team is now conducting survey of flood marks at each bridge from river mouth up to Pelaez bridge.

Table 6.1.6 shows the rough flood mark elevation estimated from pictures during the site inspection.

Table 6.1.6 Flood Mark Elevation (TY Pablo)

Name of Survey	Investigation Point	Flood Mark	Remarks
The Survey Team	Kauswagan Br.	2.60m	Datum: Macajalar Bay mean sea level
	Maharika Br.	2.62m	
	Ysalina Br.	3.69m	
	Kagay-an Br.	5.60m	

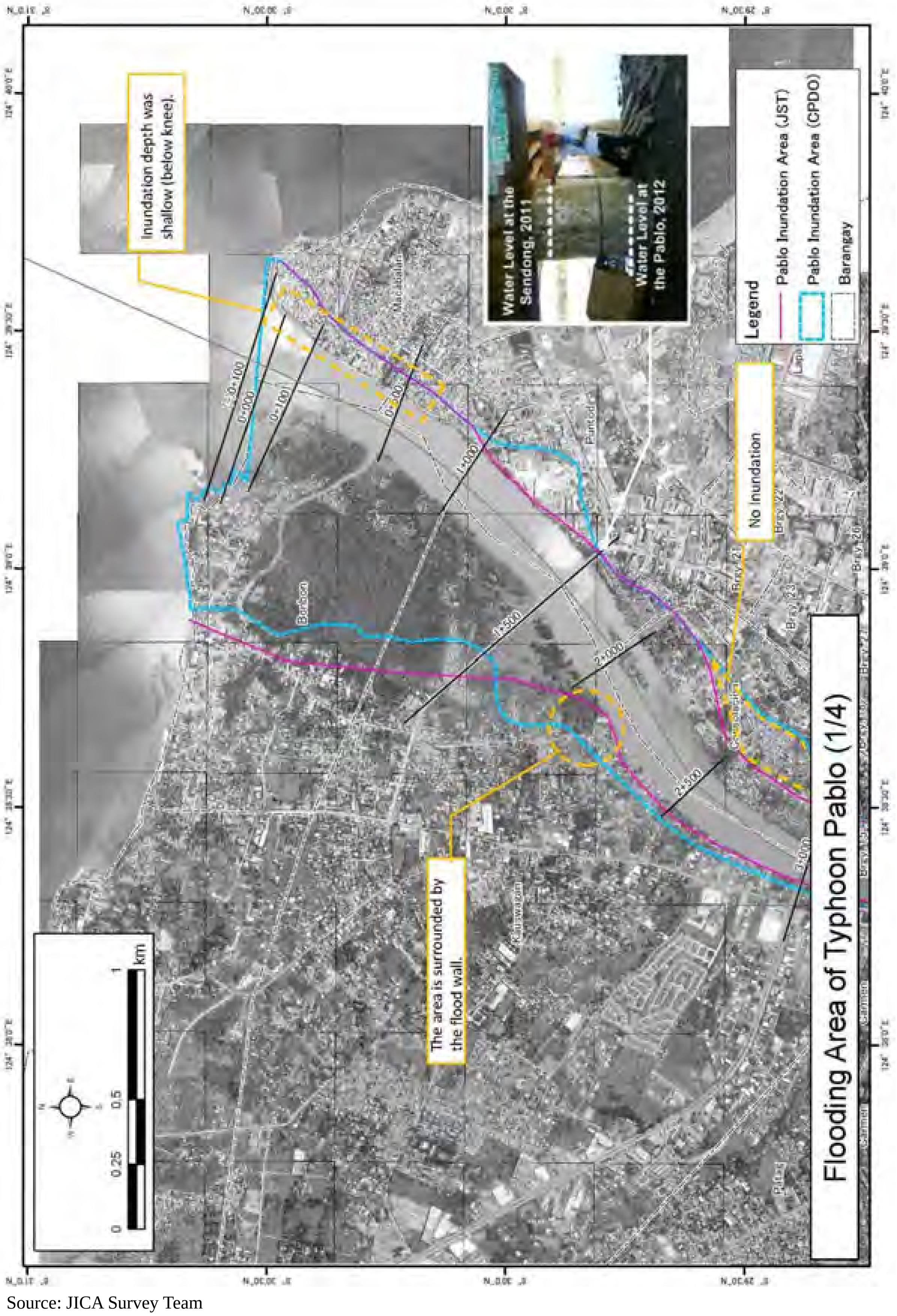
Source: JICA Survey Team

(6) Area of Inundated

The City Planning and Development Office in CDO City summarized the area of TY Pablo inundation. JICA Survey Team modified the area according to interview at the site and the geography of the river basin. Figure 6.1.9 shows the condition of inundation area of the inundated.

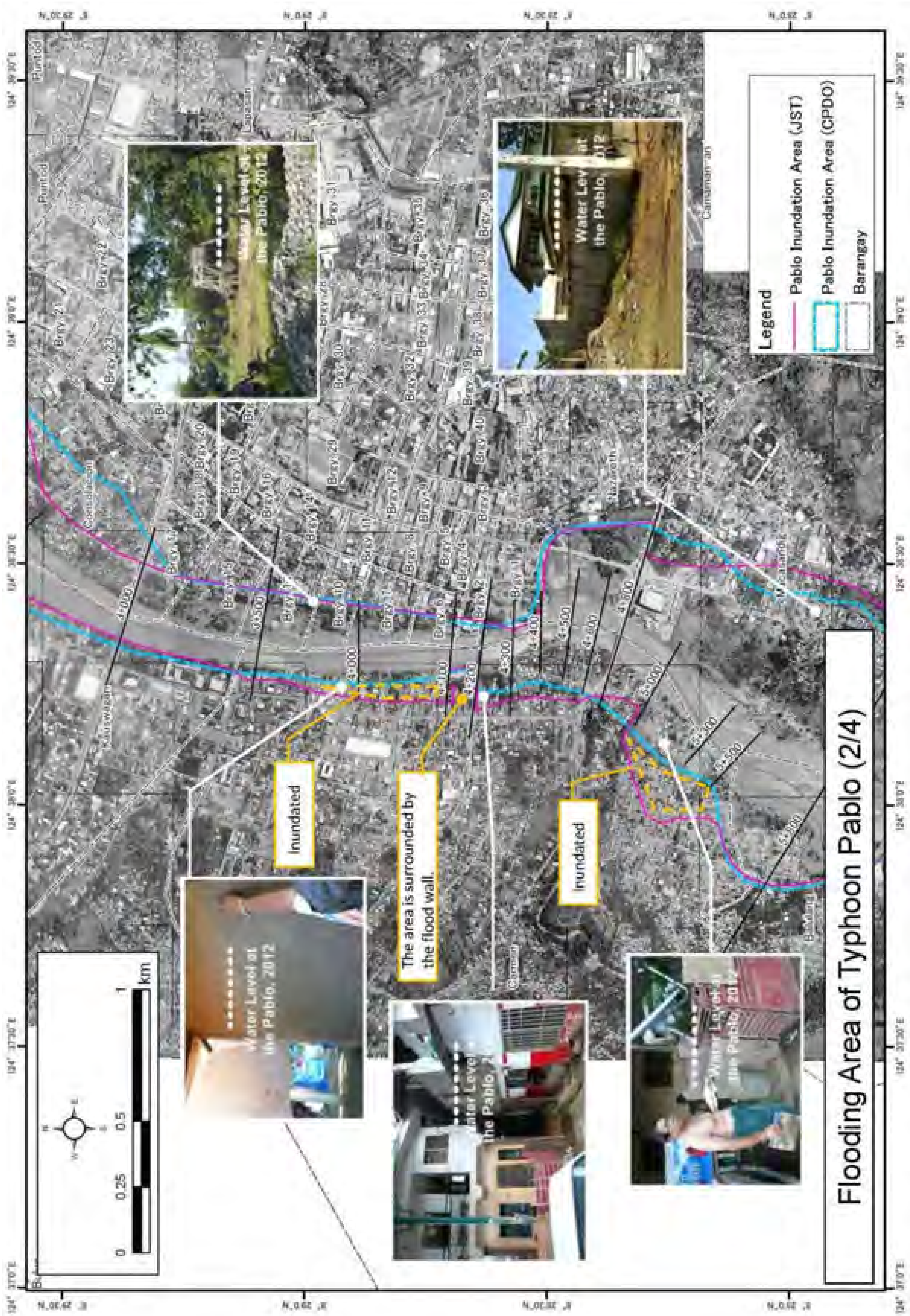
(7) Change of River Channel

JICA Survey Team provided cross section leveling in 2012 and 2013. It has done to compare both of said cross section to get the change of river channel in Appendix A.



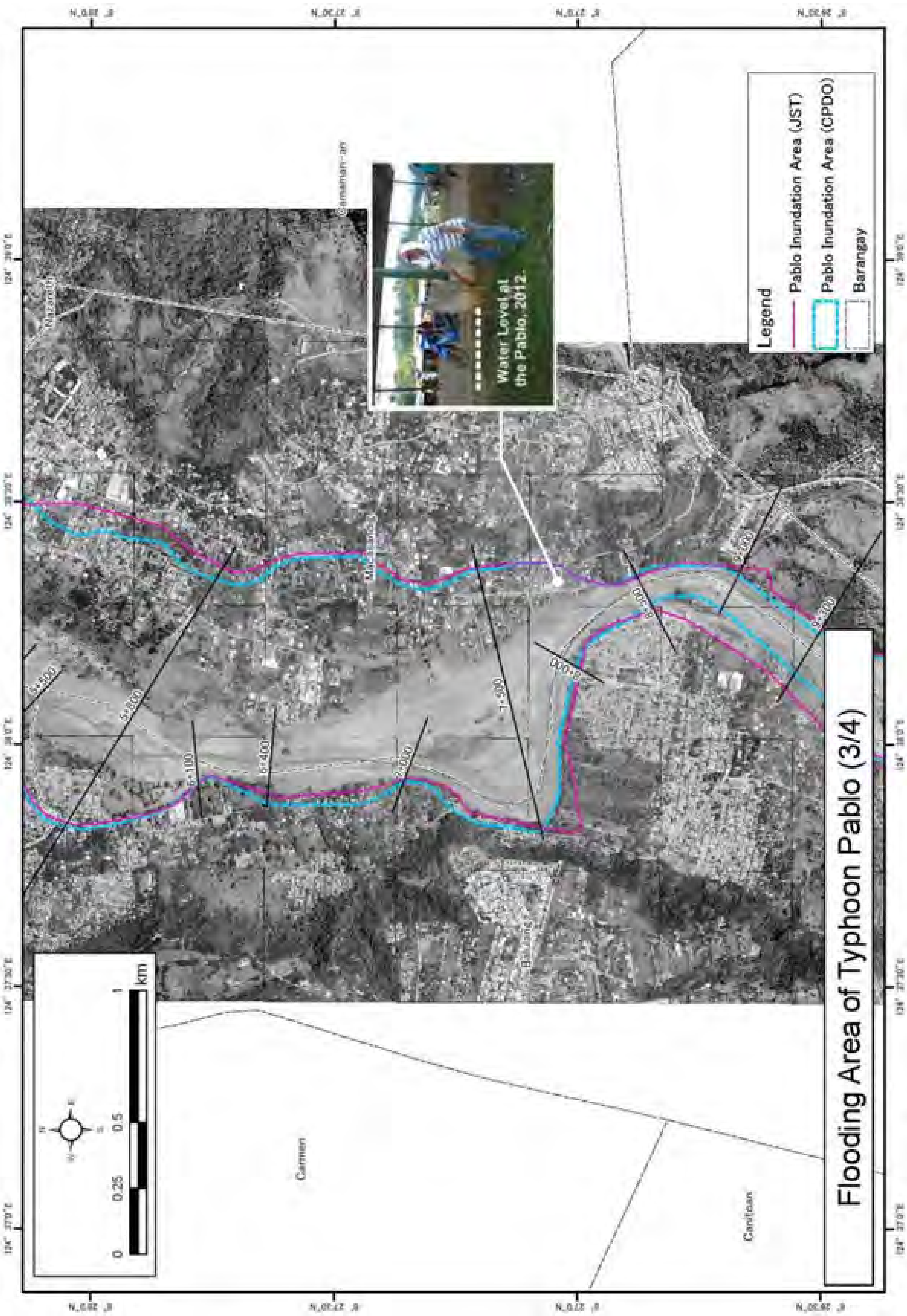
Source: JICA Survey Team

Figure 6.1.9 Inundation Depth, Area of Inundated of TY Pablo (1/4)



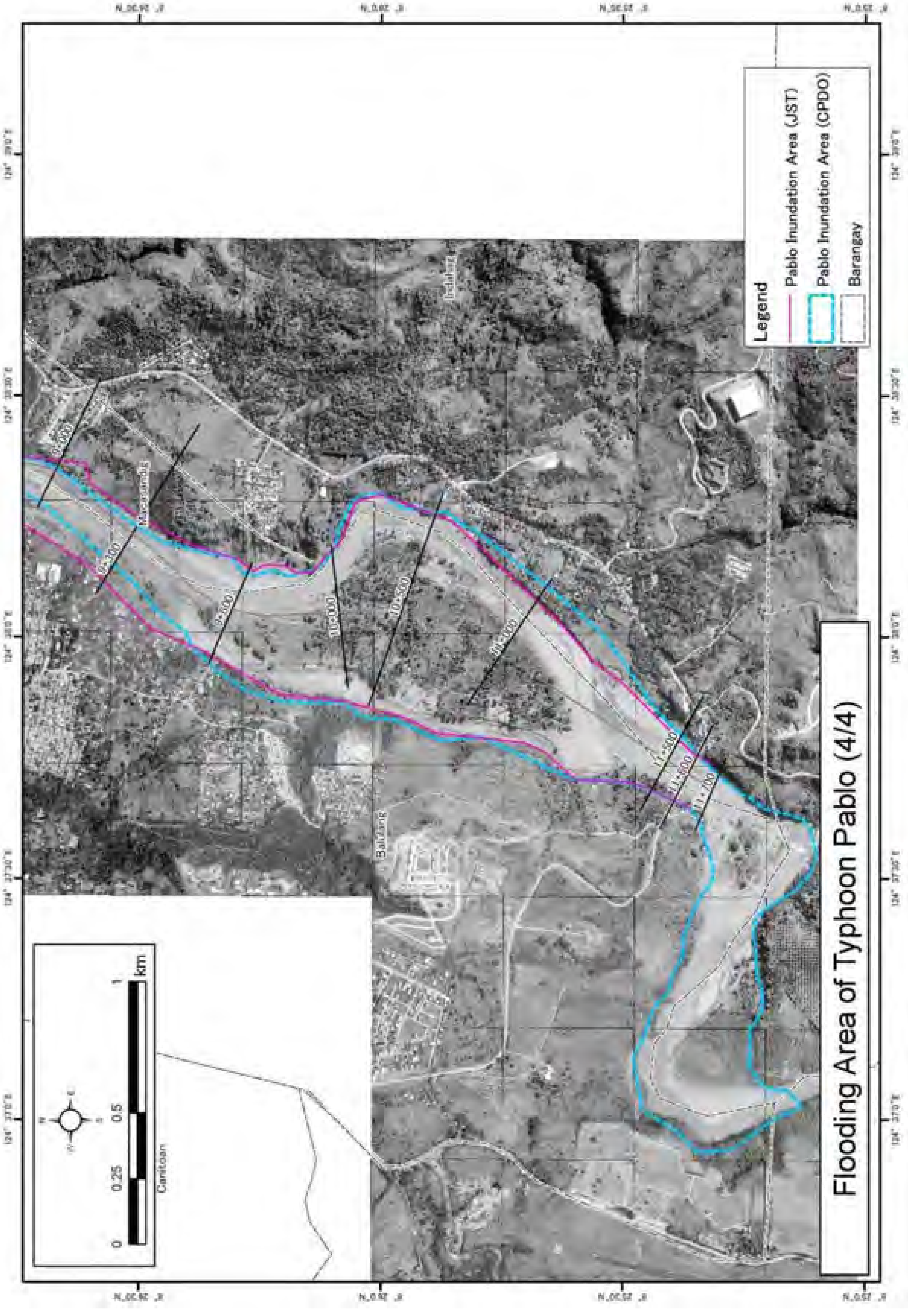
Source: JICA Survey Team

Figure 6.1.9 Inundation Depth, Area of Inundated of TY Pablo (2/4)



Source: JICA Survey Team

Figure 6.1.9 Inundation Depth, Area of Inundated of TY Pablo (3/4)



Source: JICA Survey Team

Figure 6.1.9 Inundation Depth, Area of Inundated of TY Pablo (4/4)

6.2 Geography of Floodplain

The Survey conducted the river cross section surveying and complement order leveling and 1/1,000 topography mapping. Figure 6.2.1 shows the profiles. Also, Figure 6.2.2 shows Digital Elevation Model (DEM) made by contour line of topography map and working point of cross section and leveling.

Geographic feature is broken down in three (3) zone as follows from river mouth to Pelaez Bridge where is the range for inundation analysis.

<Area 1 from river mouth to Sta.4+300 vicinity>

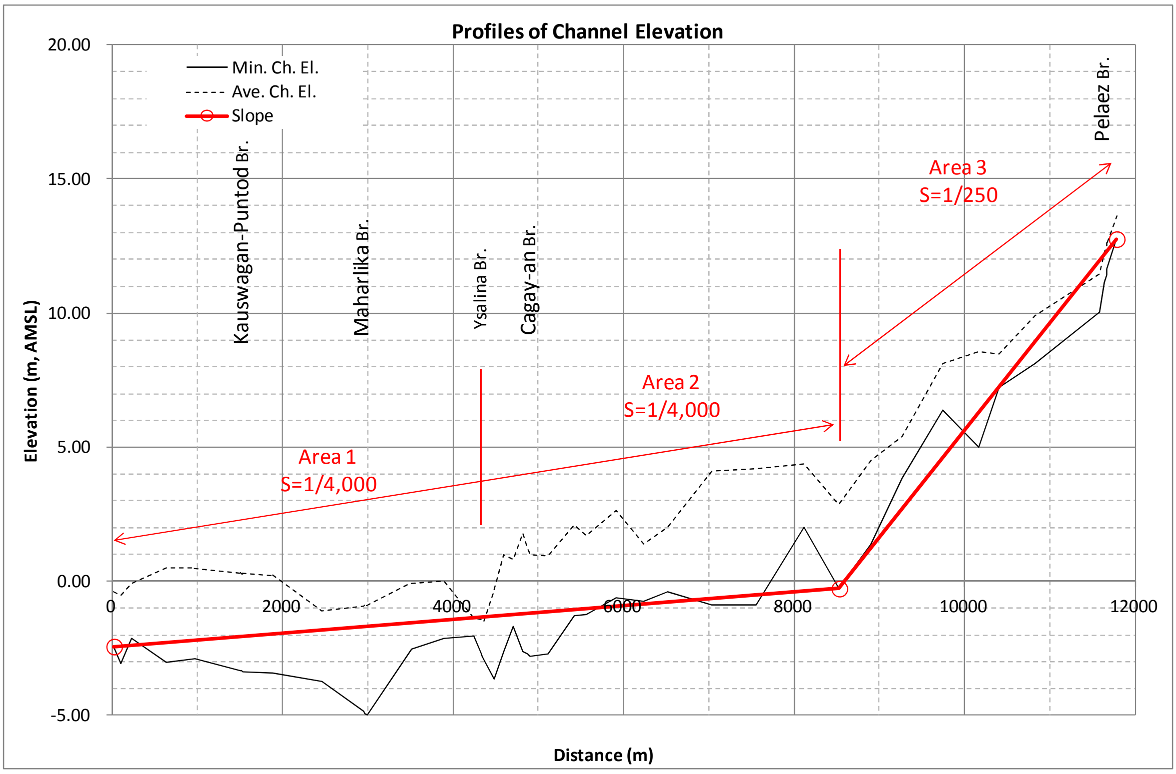
There is the constrained in the vicinity of Sta.4+300, and then downstream from that is flood plain. However, considering that longitudinal slope around 1/4,000 is steep for river mouth, it is estimated for flood flow to show the straight-line except part of the river mouth. It is also estimated that diffusional flood morphology is shown at downstream from Sta.1+500 of river mouth.

<Area 2 from Sta.4+300 to Sta.8+500 vicinity>

Because Sta.4+300 vicinity is narrow pass, flood whose width is around 1km occurred up to Sta.8+500 where is the changing point of slope. The longitudinal slope is around 1/4,000. Flood flow is presumed to be a straight-line.

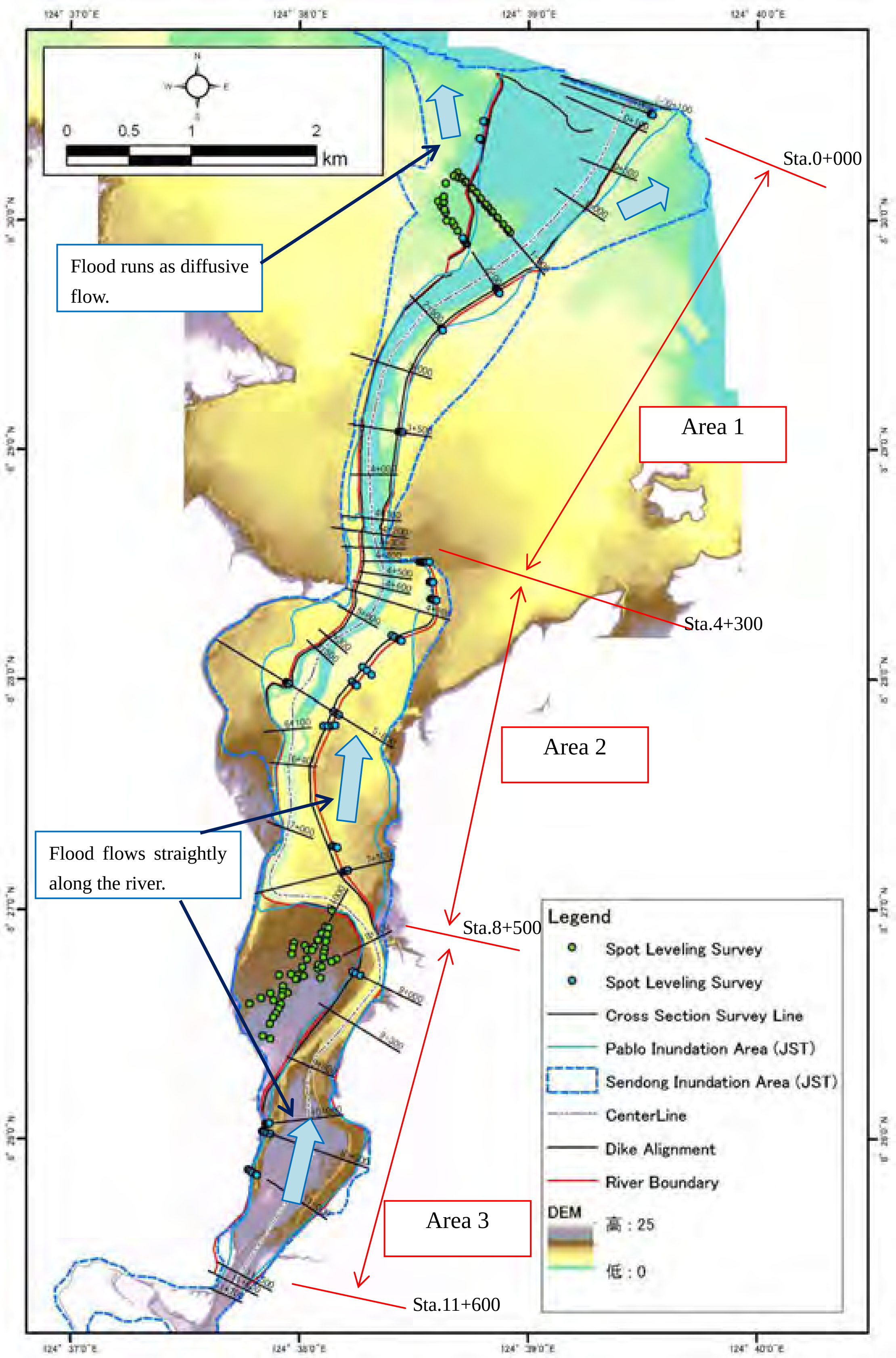
<Area 3 from Sta.8+500 to Pelaez Bridge>

The longitudinal slope is steep as around 1/250 from upstream of Sta.8+500. Therefore, the cross section and flood plain is narrow. Flood flow is presumed to be a straight-line.



Source: JICA Survey Team

Figure 6.2.1 Profile of River Mouth to Pelaez Bridge



Source: JICA Survey Team

Figure 6.2.2 Geography of River Mouth to Pelaez Bridge

6.3 Inundation Analysis

Inundation analysis model in the downstream area of the Cagayan de Oro River is formulated through calibration based on the actual results of flood inundation during TS Sendong and TY Pablo. The established inundation analysis model will be used to simulate extent of inundation area and inundation depth to estimate the flood damages in the affected area.

6.3.1 Objective Area

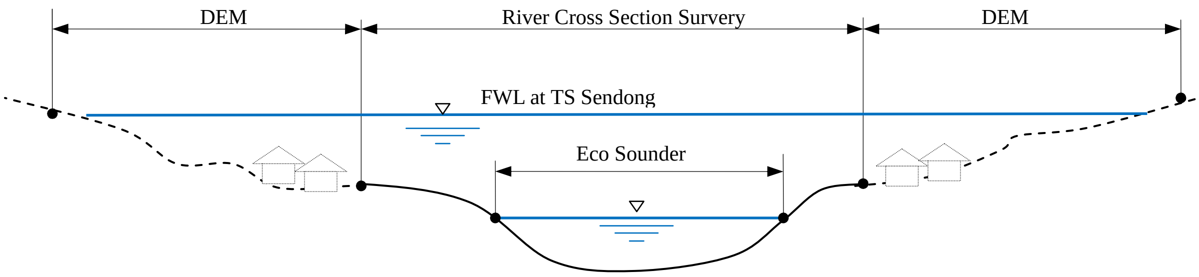
The objective area of the inundation analysis is the downstream stretch of the Cagayan de Oro River from the river mouth to the Pelaez Bridge located at Sta.11+600.

6.3.2 Inundation Analysis Model

The flood inundation type in the objective area is basically classified into “flowing down type”. Hydraulic characteristics of the flowing down type flood inundation can be simulated adopting a one-dimensional hydraulic analysis model. In this study, the inundation analysis model is applied the one-dimensional unsteady flow analysis model of the HEC-RAS (Hydrologic Engineering Center - River Analysis System) which is currently being used by various agencies in the nation-wide of the Philippines .

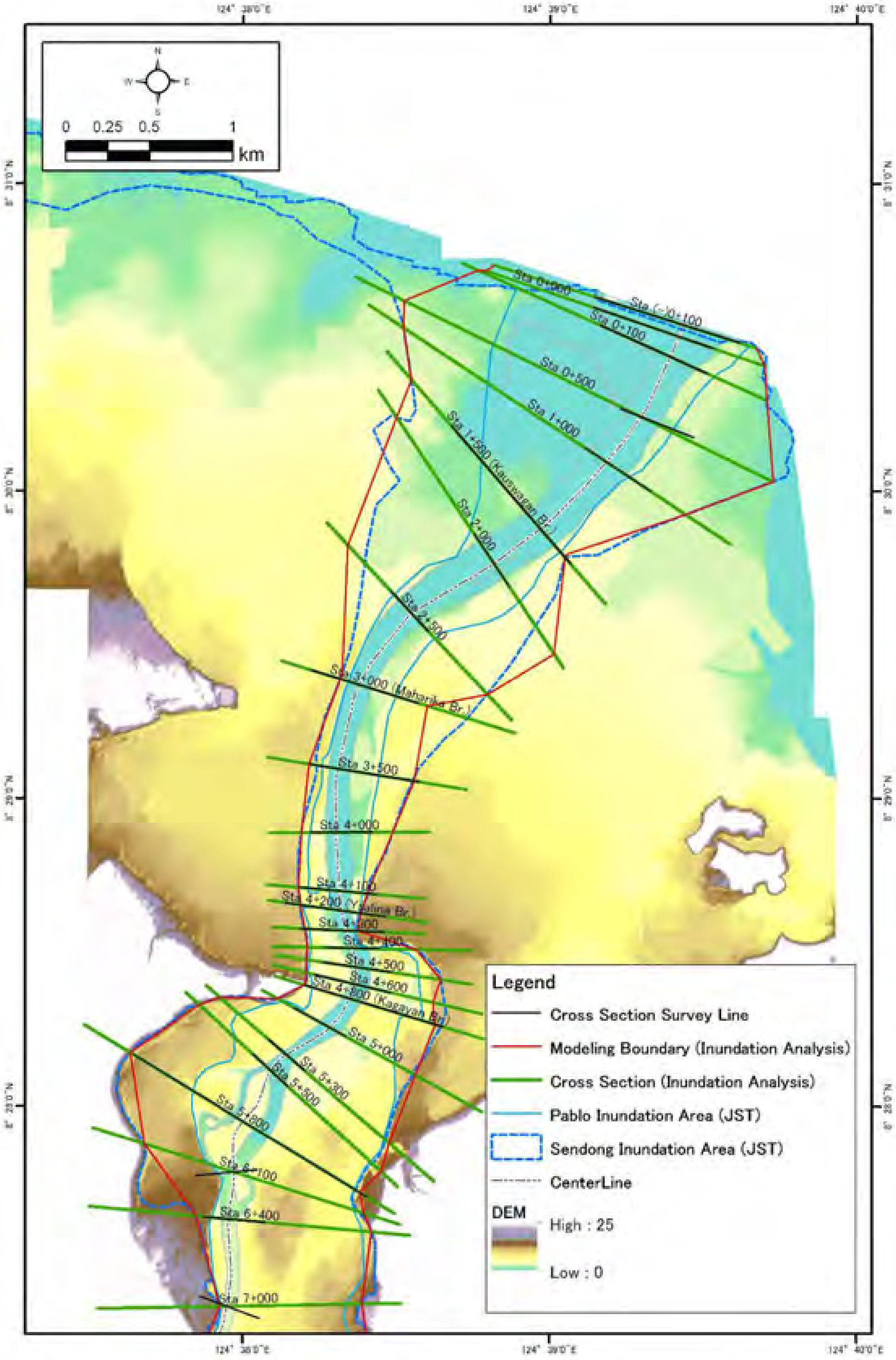
6.3.3 Cross Section Data

The 37 cross sections data surveyed in this study in November 2012 are used for the inundation analysis model. Since the river cross section survey was conducted along the river channel, topographic data in the inundation area located outer side of the extent of the river cross section is generated from the DEM which was prepared based on the contour data of the latest topographic map with 1/1000 scale prepared in the Survey. The extent of cross section is set up to the flood inundation area during the TS Sendong. The cross section model is presented in figure below:



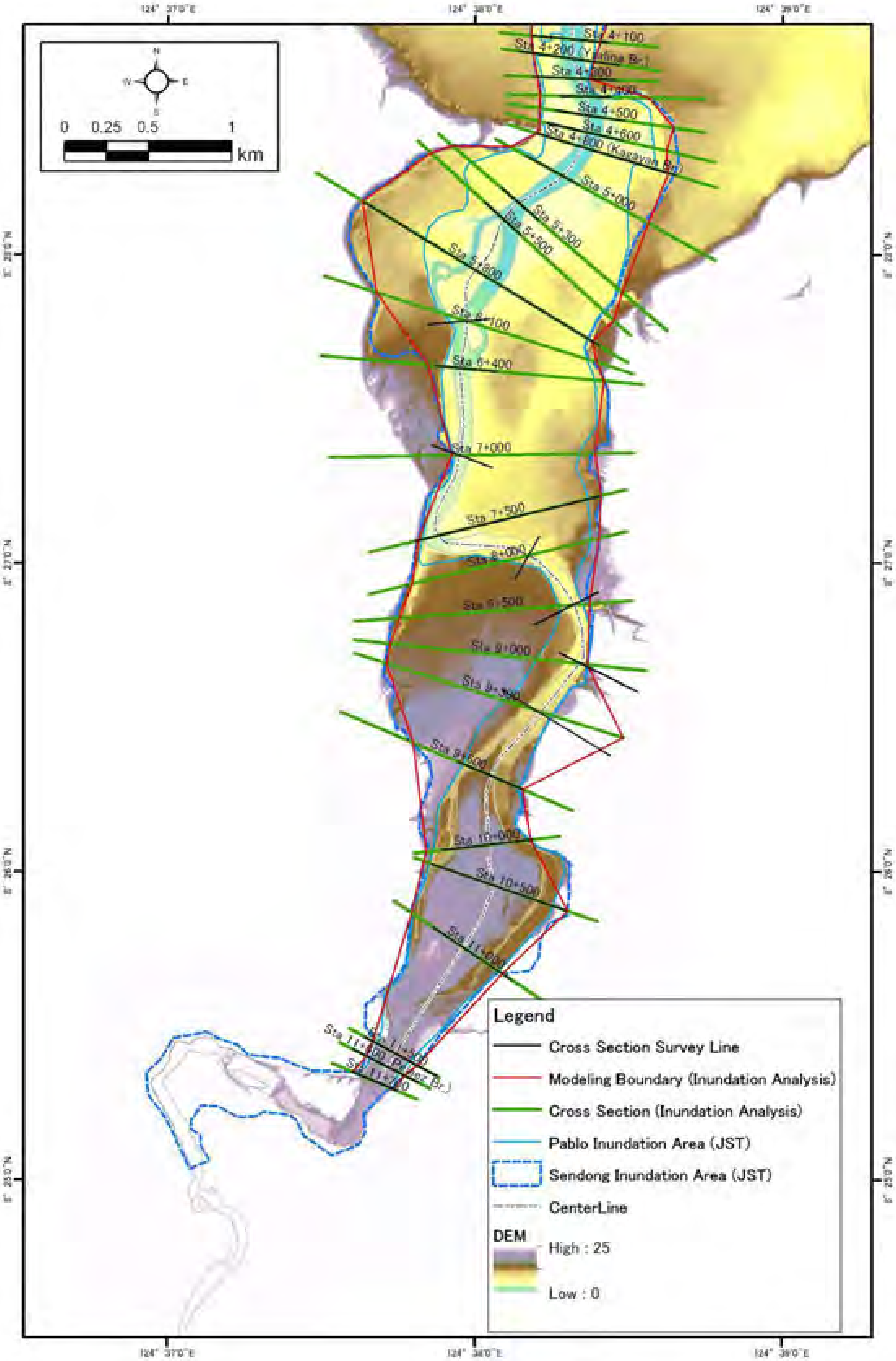
Source: JICA Survey Team

Figure 6.3.1 Method of Preparation of Cross Section Data for Hydraulic Analysis



Source: JICA Survey Team

Figure 6.3.2 Boundary of Inundation Model (1/2)



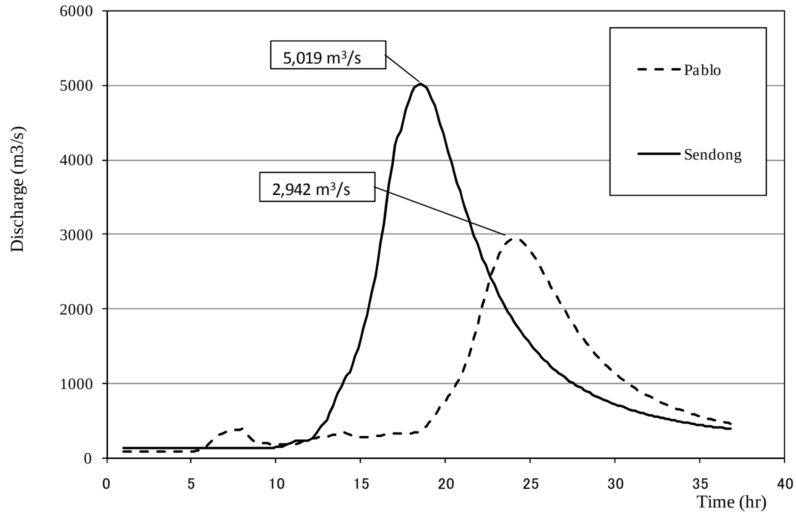
Source: JICA Survey Team

Figure 6.3.3 Boundary of Inundation Model (2/2)

6.3.4 Conditions of Runoff

(1) Storm Discharge in the Basin (Storms of Pablo and Sendong)

Actual flood hydrographs recorded at typhoon Pablo and tropical storm Sendong are used for study on the design hydrograph in the Cagayan de Oro River basin. Design flood hydrograph is assumed based on basin rainfall - runoff analysis at Kauswagan Bridge in Cagayan de Oro City, which need to be derived from the rainfall – runoff model because flood water level has not been measured in the study area.

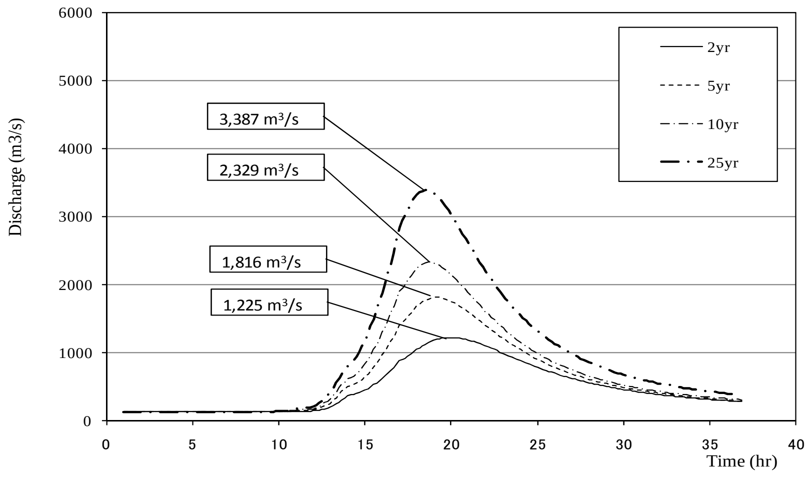


Source: JICA Survey Team

Figure 6.3.4 Hydrograph of Storm Discharge estimated by Runoff Model (at Kauswagan Bridge)

(2) Design Storm Discharge in the Basin (Discharges by Flood Return Period)

River channel improvement plan is formulated under the design flood discharge of 25-year return period. Accordingly one dimensional non-steady flow analysis should be conducted based on design hydrograph derived through rainfall-runoff analysis at the Kauswagan Bridge, in which four (4) cases of flood discharges of 2-year, 5-year, 10-year and 25-year return period are used for the study.



Source: JICA Survey Team

Figure 6.3.5 Design Flood Hydro Graph (at Kauswagan Brdige)

6.3.5 Other Conditions

(1) Roughness Coefficient

The following roughness coefficients (n) are applied for the runoff analysis referring to design standards of DPWH and HEC-RAS. The roughness coefficient at each river cross section for the runoff analysis is shown in Figure 6.3.6.

Table 6.3.1 Roughness Coefficient (n)

General Classification		n
1	River Channel（Sta.0+000 - Sta.4+800）	0.030
	River Channel（Sta.5+000 - Sta.11+700）	0.035
2	Sand bar with vegetation	0.055
3	Flood plain with grass/brush	0.045
4	Flood plain with medium to dense houses and buildings	0.090

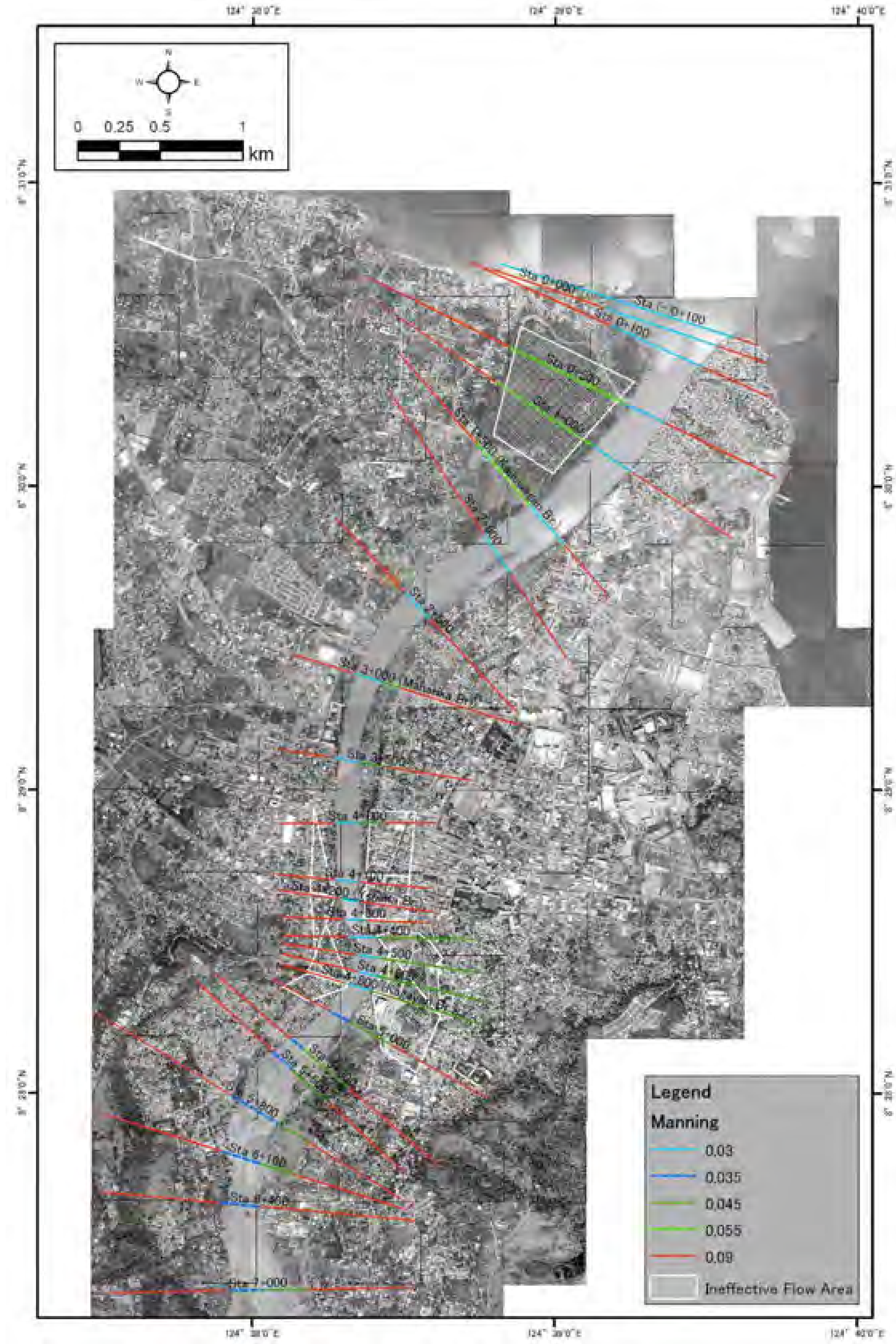
Source: JICA Survey Team

(2) Tide Level

Measured tide level is applied for runoff / hydraulic analysis on storm discharges of Sendong and Pablo. On the other hand, average high tide level (mean sea level of MSL=1.01m) should be applied for runoff analysis in each flood return period.

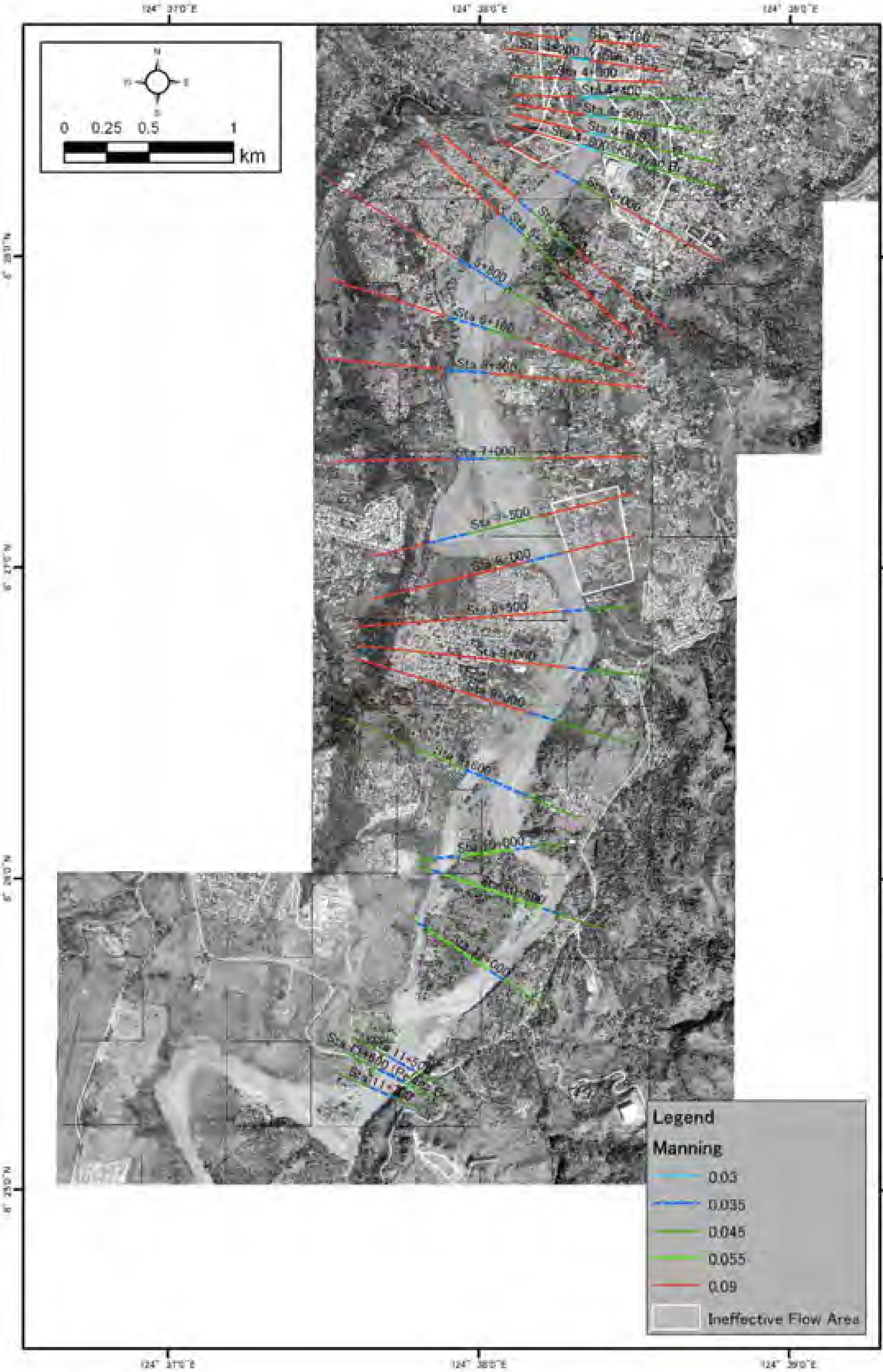
(3) Ineffective Flow Area

Ineffective flow area is set by five (5) degree and twenty six (26) degree for rapid-enlarge and rapid-contraction to ordinary-river flow respectively. Ineffective flow area for the runoff analysis is shown in Figure 6.3.6.



Source: JICA Survey Team

Figure 6.3.6 Roughness Coefficient and Dead Zone (1/2)



Source: JICA Survey Team

Figure 6.3.6 Roughness Coefficient and Dead Zone (2/2)

6.3.6 The Results of Inundation Analysis for Typhoon Sendong and Pablo

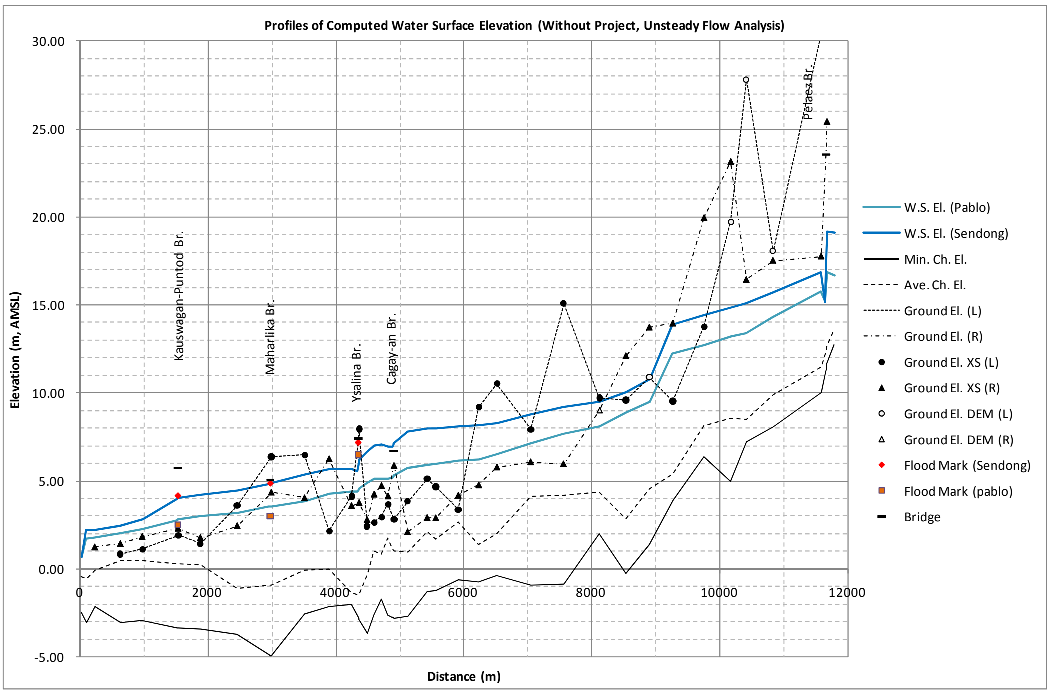
Figure 6.3.7 shows the estimated water level distribution during typhoon Sendong and Pablo, in addition Figure 6.3.8 shows the estimated inundation depths during typhoon Sendong, and Figure6.3.9 shows that of Pablo.

The analysis was done with one dimensional hydraulic calculation. Therefore, inundation depth rank map was made by the following method.

1) Water levels at any point on the survey lines are estimated with linear interpolation based on the calculated values on the survey lines. The format of the dataset is a meter mesh.
2) Inundation depths are obtained from calculating the difference between the water level derived in 1) and the ground elevation (DEM).
3) Inundation depth distribution of each occurrence frequencies for estimating damages is a meter mesh. It is obtained by averaging inundation depths above.

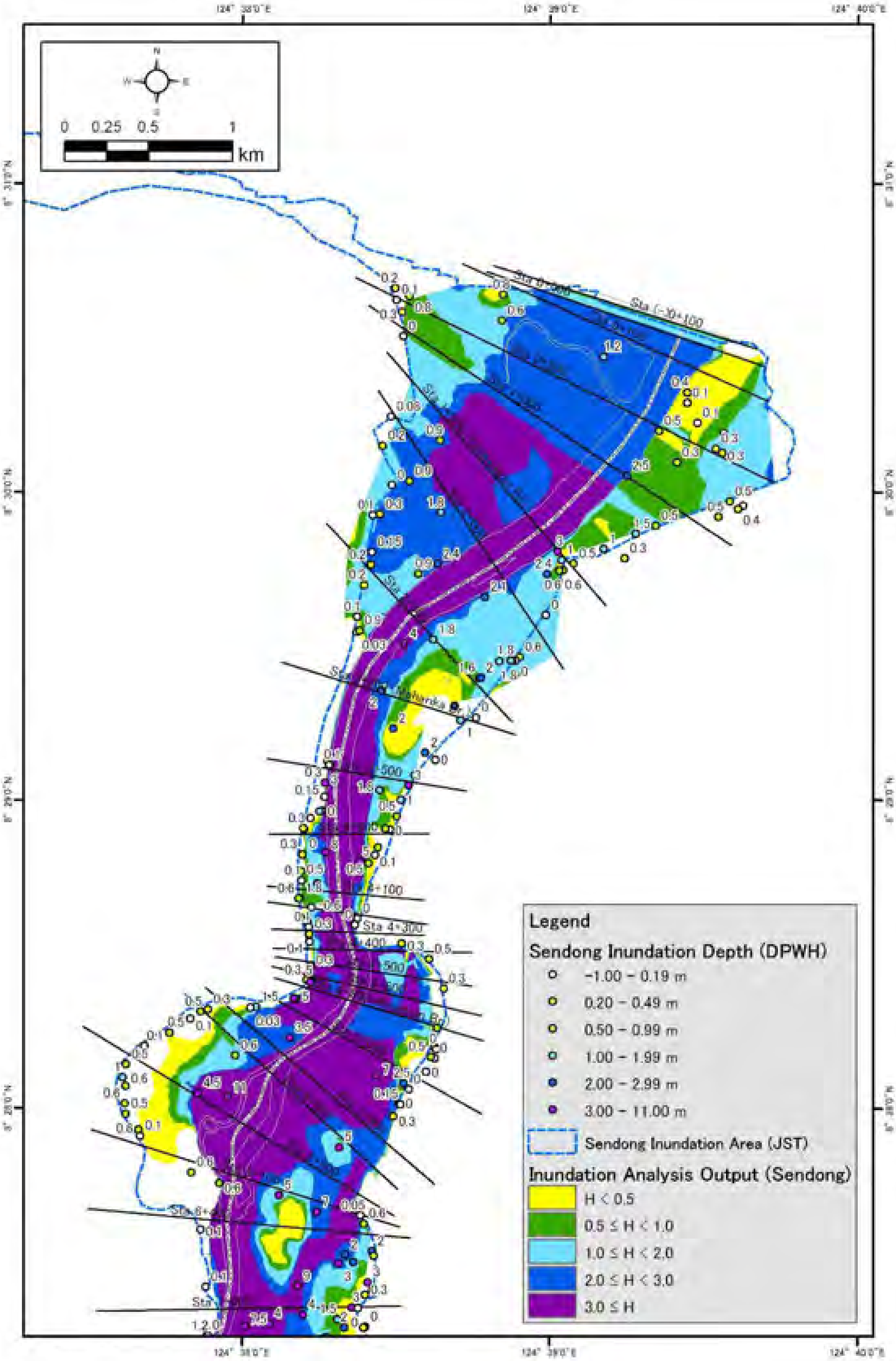
In the case of Sendong Analysis, the estimated water levels are consistent with flood marks between Kauswagan Bridge and Maharlika Bridge, while they are about a meter lower than them at Ysalina Bridge. The estimated inundation depths are consistent with the results of the survey about the actual past inundation areas and depths. However, they tend to be higher than actual above the Ysalina Bridge, while they do lower than actual below it.

In regard to Pablo Analysis, the trend is as same as Sendon Analysis. The estimated water levels are consistent with flood marks between Kauswagan Bridge and Maharlika Bridge, while they are about a meter lower than them at Ysalina Bridge. The estimated inundation depths are consistent with the results of the survey about the actual past inundation areas and depths. However, they tend to be higher than actual above the Ysalina Bridge, while they do lower than actual below it.



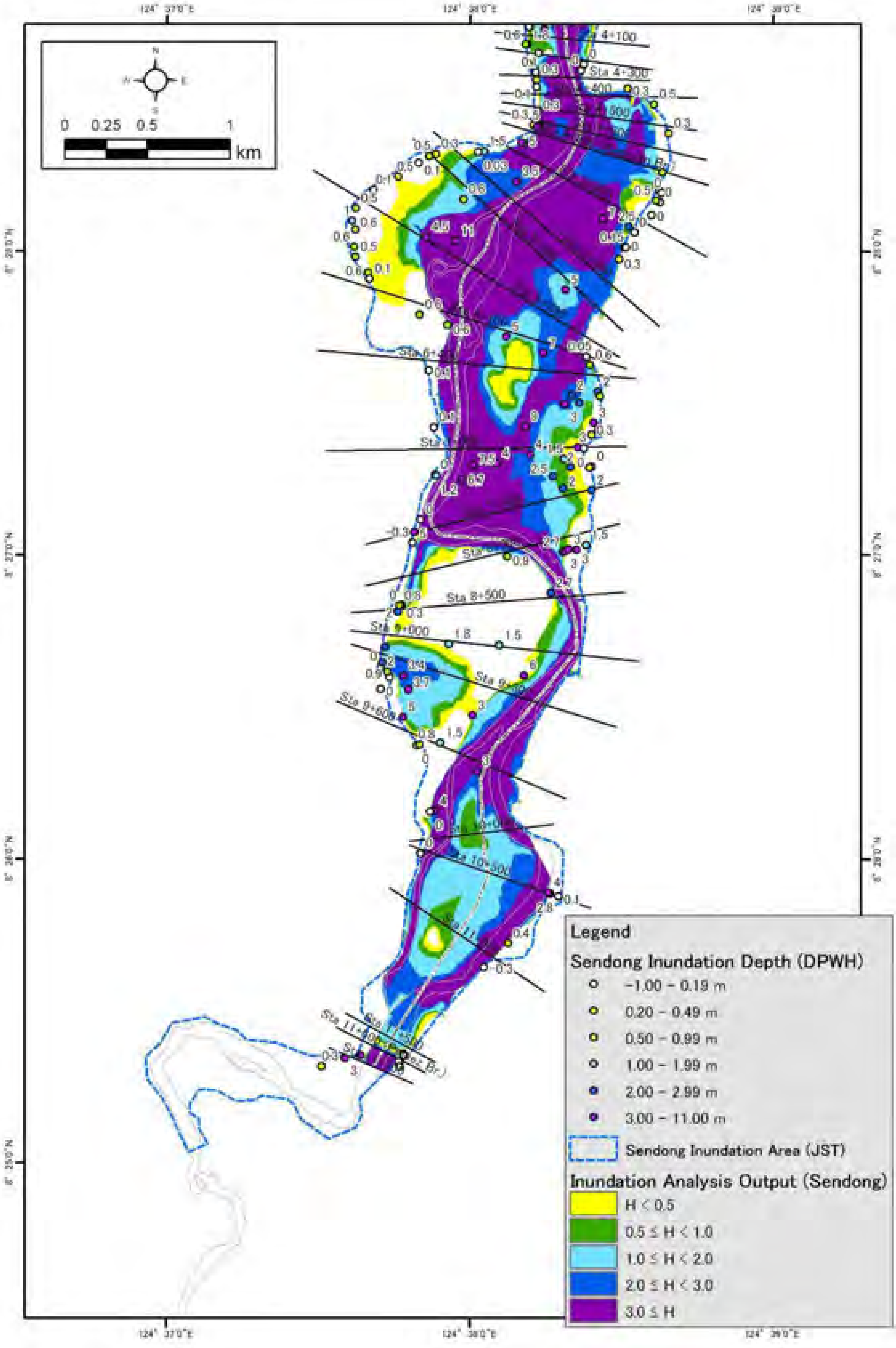
Source: JICA Survey Team

Figure 6.3.7 TS Sendong / TY Pablo Estimated Water Level Distribution



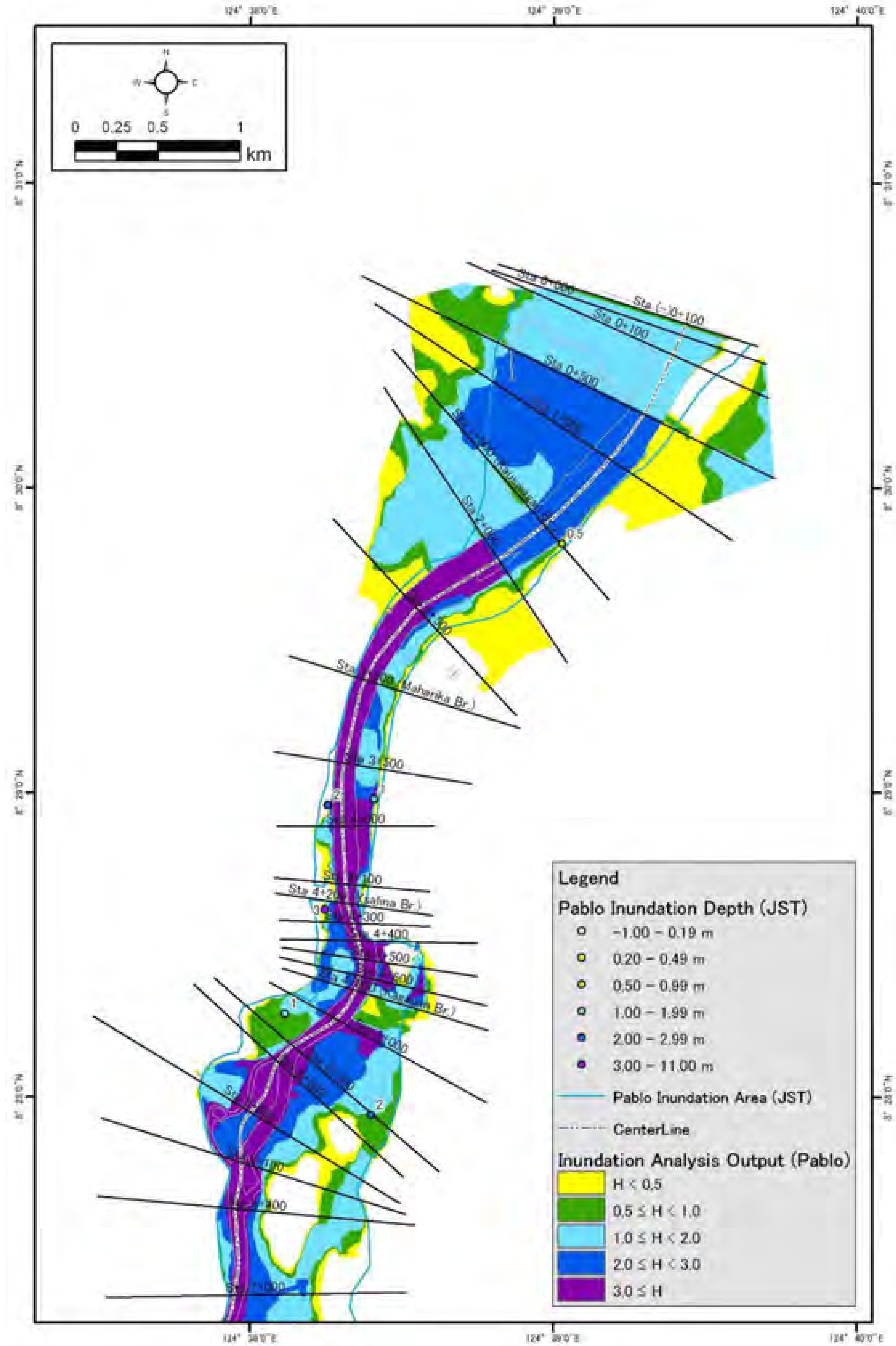
Source: JICA Survey Team

Figure 6.3.8 TS Sendong Estimated Inundation Depth (1/2)



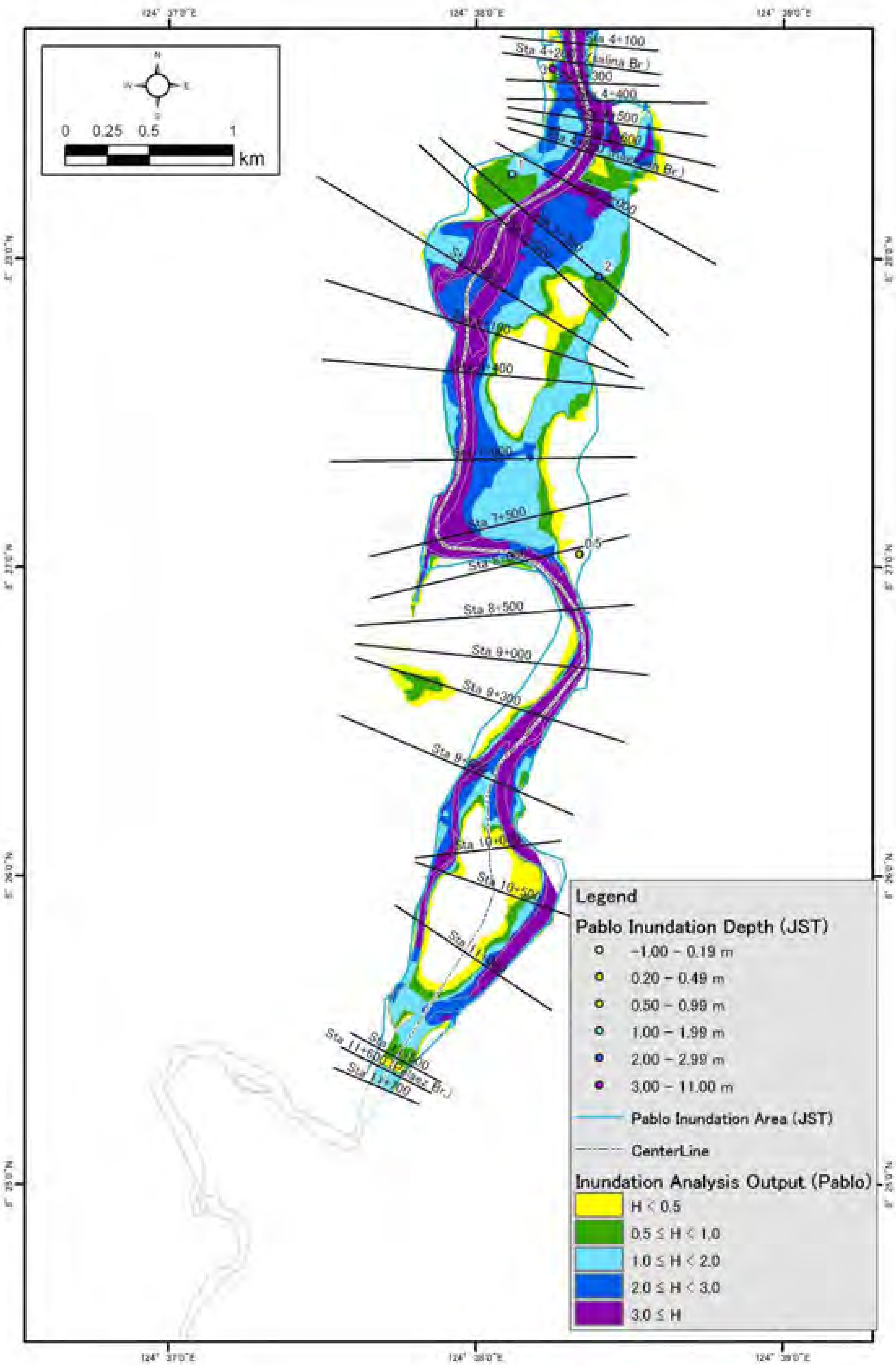
Source: JICA Survey Team

Figure 6.3.8 TS Sendong Estimated Inundation Depth (2/2)



Source: JICA Survey Team

Figure 6.3.9 TY Pablo Estimated Inundation Depth (1/2)



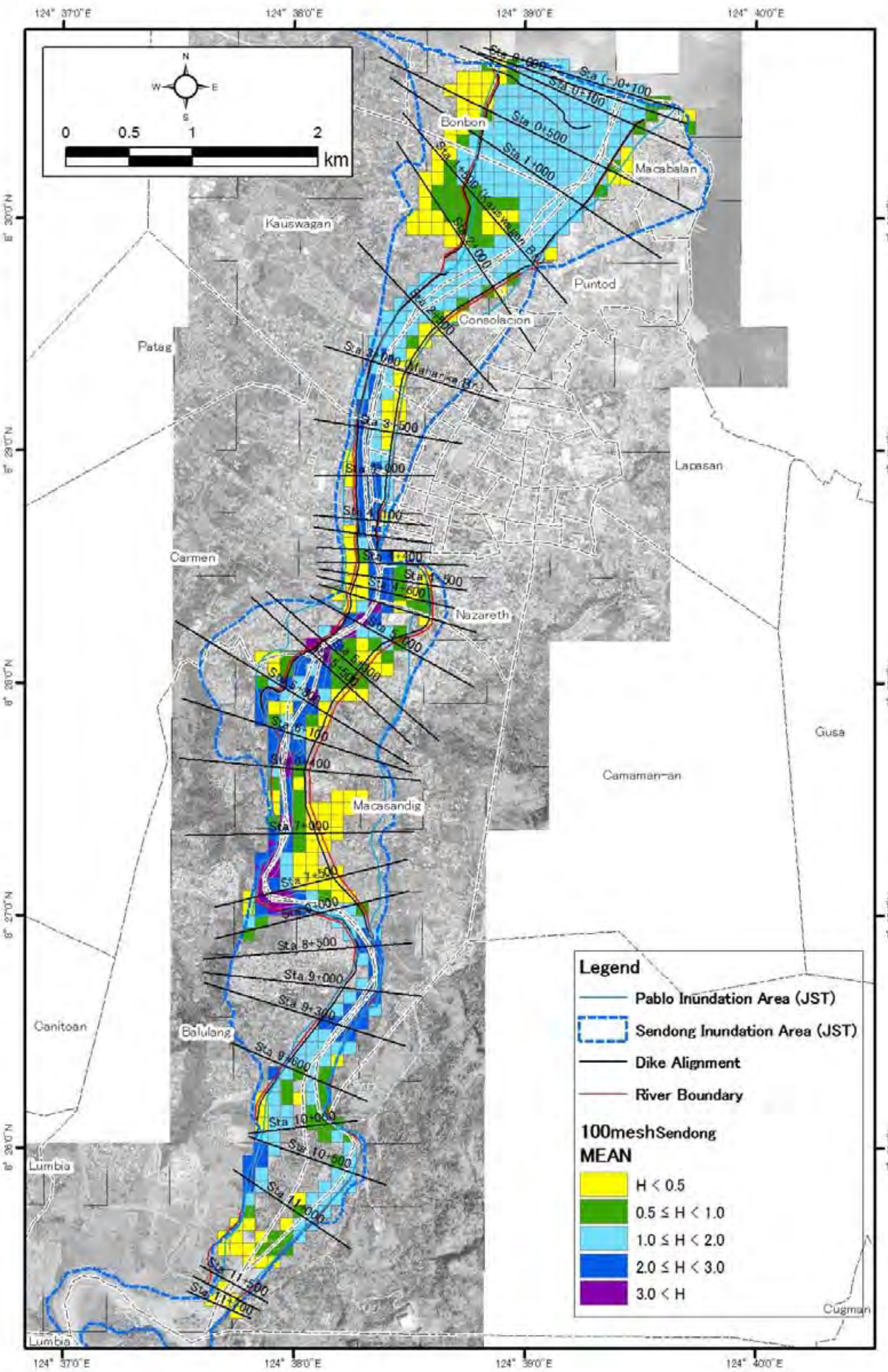
Source: JICA Survey Team

Figure 6.3.9 TY Pablo Estimated Inundation Depth (2/2)

6.3.7 The Result of Flood Inundation Analysis (Design Scale Alternatives)

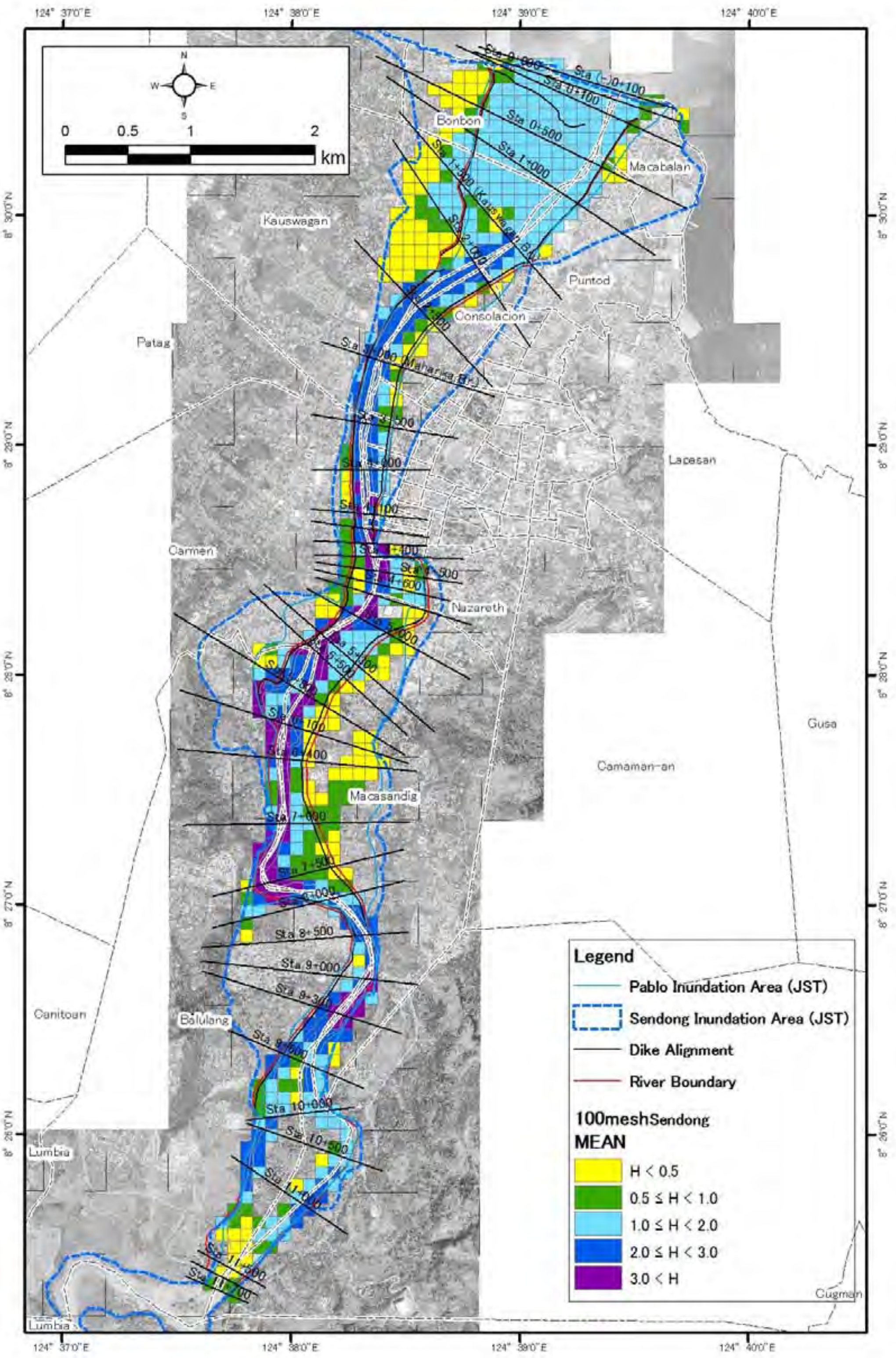
In Economic Analysis mentioned later, the inundation depth (H) is evaluated per 100 m squares and classified into five (5) ranks of i) H<0.5m, ii) 0.5m≦H<1.0m, iii) 1.0m≦H<2.0m, iv) 2.0 m≦H<3.0m and v)3.0 m <H. The inundation maps of 1/2, 1/5, 1/10 and 1/25 and 1/50 probable flood used for the economic analysis are shown in Figure 6.3.10, respectively.

Comparing the results of inundation analysis with the actual inundation areas of TY Pablo and TS Sendong, the inundation areas of 1/25 and 1/50 probable floods are corresponding well to those of TY Pablo and TS Sendong respectively.



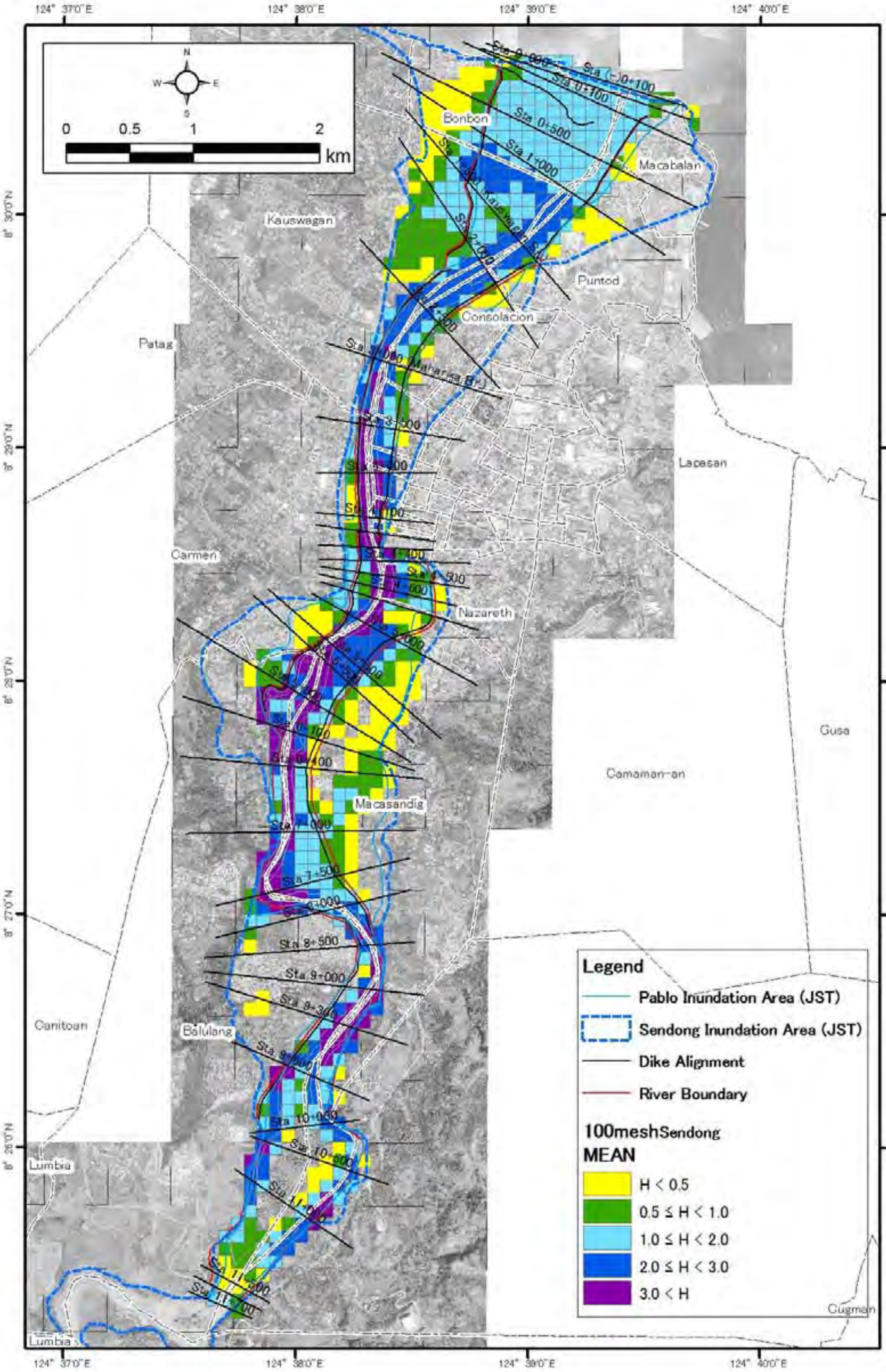
Source: JICA Survey Team

Figure 6.3.10 Result of Inundation Analysis for Each Design Scale Alternatives (2 years)



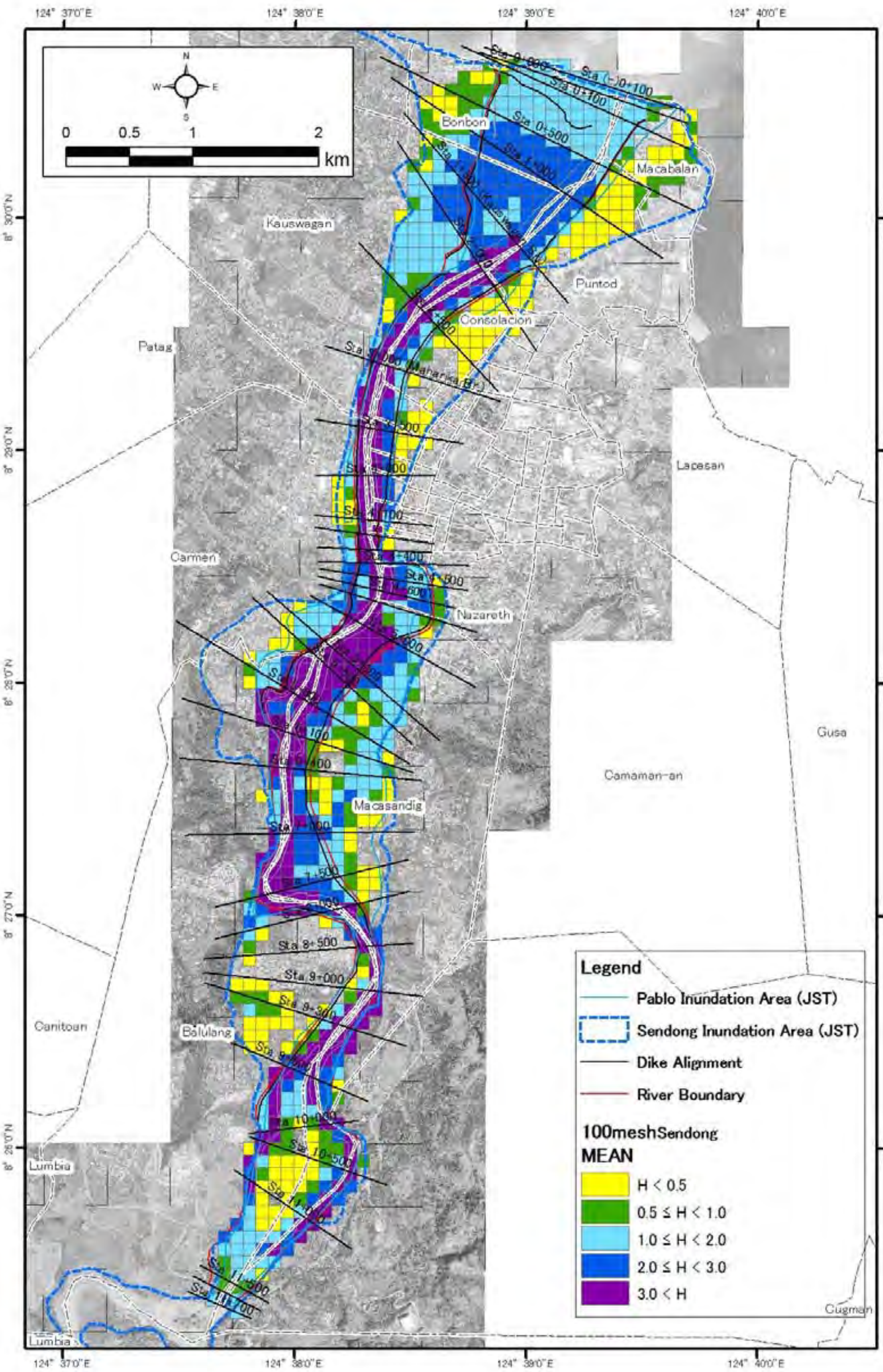
Source: JICA Survey Team

Figure 6.3.10 Result of Inundation Analysis for Each Design Scale Alternatives (5 years)



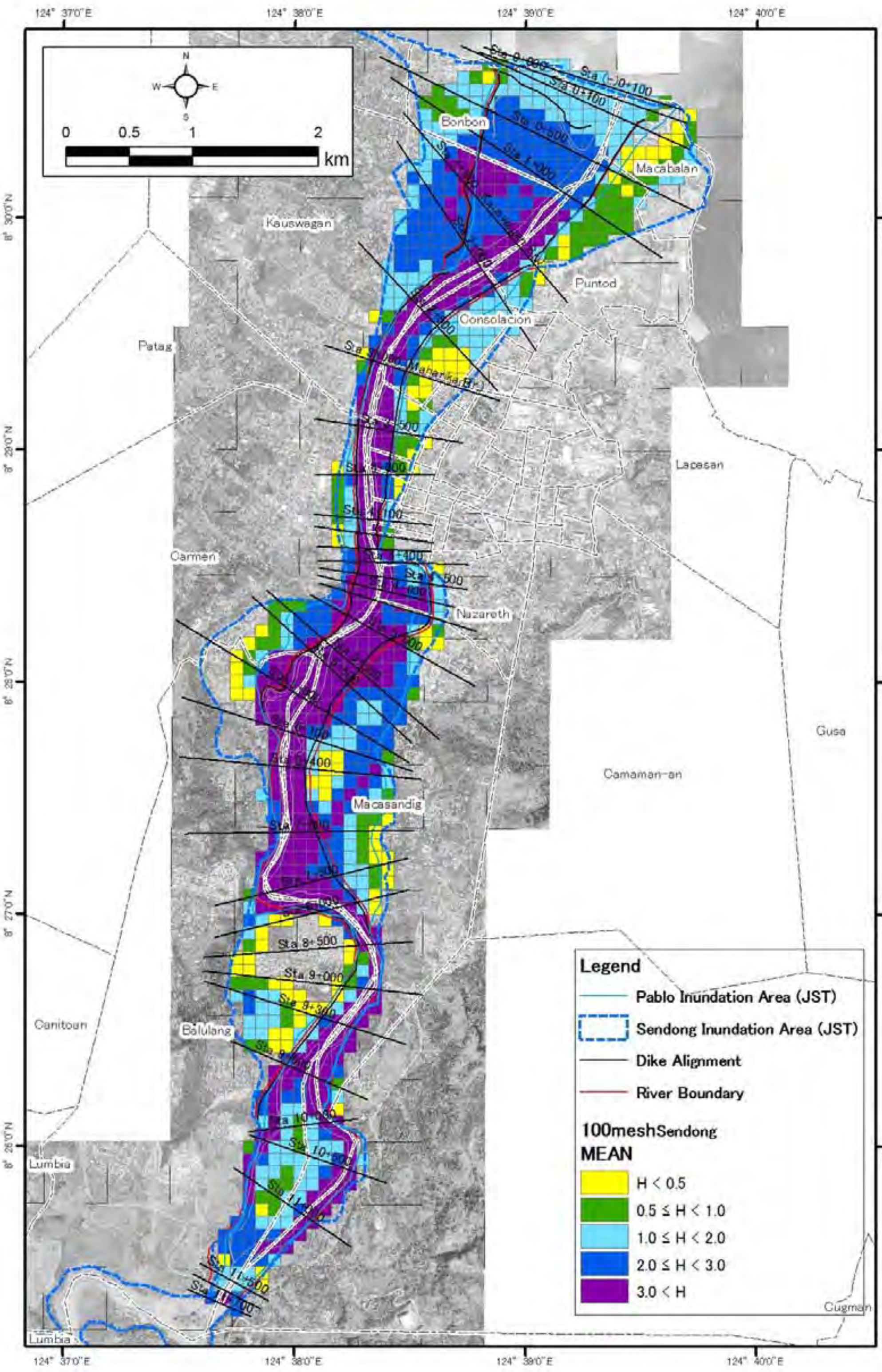
Source: JICA Survey Team

Figure 6.3.10 Result of Inundation Analysis for Each Design Scale Alternatives (10 years)



Source: JICA Survey Team

Figure 6.3.10 Result of Inundation Analysis for Each Design Scale Alternatives (25 years)



Source: JICA Survey Team

Figure 6.3.10 Result of Inundation Analysis for Each Design Scale Alternatives (50 years)

6.4 Study for Riverbed Movements

6.4.1 Present situation of sedimentation in river mouth

The figure below shows the historical change of the river mouth of the Cagayan de Oro River comparing with the topographic maps prepared by NAMRIA in 1950's and in 2011. The coastal line adjacent of the river mouth is moving toward the Macajalar Bay with development of the delta.

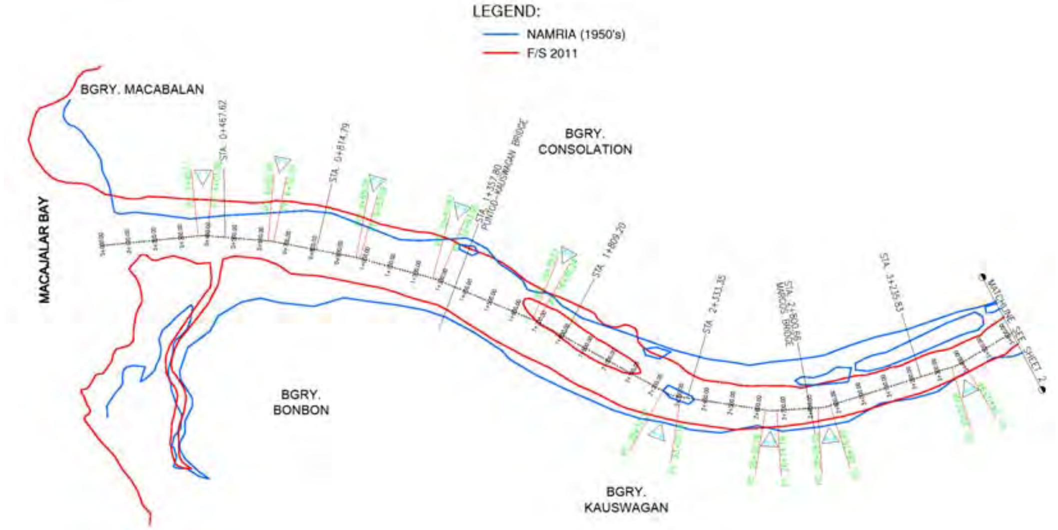
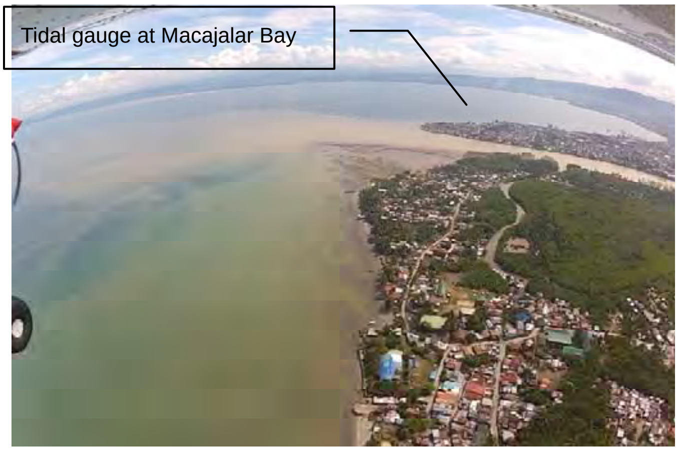


Figure 6.4.1 Historical Change of River Mouth in Cagayan de Oro River

The aerial photo of the river mouth indicates the turbidity water from the river penetrating into the river mouth. According to the local sand mining operators and local residents during the site reconnaissance, it was informed that the riverbed in the downstream of the river is getting shallower than the previous situation. The staff of the Port Authority and a chief of pilot who have worked in this area since long before mentioned that the ship could voyage along the coastal side but it is impossible at present due to development of shallow areas along the coastal line. They also stated that the periodic maintenance dredging is being conducted at the harbor in the port located at around 1 km east of the river mouth.



Source: PARASAT

Figure 6.4.2 Aerial Photo of River Mouth of Cagayan de Oro River (taken after TY Pablo in January 2013)

6.4.2 Existing Data of Cross Section Survey

(1) Existing Data

River cross section surveys along the Cagayan de Oro River were conducted three times since 2011, including the second and third ones carried out in the Survey.

The location map of these cross section surveys is presented in Figure 6.4.3.

Table 6.4.1 Cross Data of Cross Section Survey

Cross Section Survey	Date of Survey	Survey Area, Bench Mark	Status
Previous F/S in 2011 By DPWH	April –June, 2010	BM: NAMRIA BM5 (+2.677 m above MLLW*) Cross Section : 28sections (from River mouth to Pelaez Bridge @500m)	Before TS Sendong
This Survey By JICA	October – November , 2012	BM: NAMRIA Tidal Gauge at CDO port (above MSL) Longitudinal Profile : 12 km Cross Section : 38 sections (from River mouth to Pelaez Bridge @100-500m)	After TS Sendong, before TY Pablo
This Survey By JICA	July –August, 2013	BM: NAMRIA Tidal Gauge at CDO port (above MSL) Longitudinal Profile : 12 km Cross Section : 38 sections (from River mouth to Pelaez Bridge @100-500m)	After TY Pablo

(2) Comparable Sections

As the result of preliminary assessment of each cross section data, comparable cross section data in each survey are summarized in the table below.

Table 6.4.2 Comparable Cross Section Data

Sta. No.	Crosse sections in 2011	Crosse sections in 2012	Crosse sections in 2013
STA (-)0+100	x	○	n.a.
STA 0+000	x	○	n.a.
STA 0+100	x	○	○
STA 0+500	x	○	○
STA 1+000	○	○	○
STA 1+500	○	○	○
STA 2+000	x	○	○
STA 2+500	x	○	○
STA 3+000	○	○	○
STA 3+500	x	○	○
STA 4+000	x	○	○
STA 4+100	x	○	○
STA 4+200	○	○	○
STA 4+300	x	○	○
STA 4+400	x	○	n.a.
STA 4+500	x	○	○

Sta. No.	**Crosse sections in 2011**	**Crosse sections in 2012**	**Crosse sections in 2013**
STA 4+600	x	〇	n.a.
STA 4+800	〇	〇	〇
STA 5+000	x	〇	〇
STA 5+300	〇	〇	n.a.
STA 5+500	〇	〇	〇
STA 5+800	〇	〇	〇
STA 6+100	x	〇	〇
STA 6+400	〇	〇	〇
STA 7+000	x	〇	〇
STA 7+500	x	〇	〇
STA 8+000	〇	〇	n.a.
STA 8+500	〇	〇	〇
STA 9+000	x	〇	〇
STA 9+300	〇	〇	n.a.
STA 9+600	〇	〇	〇
STA 10+000	x	〇	n.a.
STA 10+500	x	〇	〇
STA 11+000	x	〇	n.a.
STA 11+500	x	〇	n.a.
STA 11+600	x	〇	n.a.
STA 11+700	x	〇	n.a.

〇 : comparable , x : impossible, n.a.: not available

Since there is a discrepancy on the survey datum and alignment of survey section in 2011 comparing with the ones in 2012 and 2013, it is judged that some cross sections in 2011 cannot be used for comparison. The comparison of cross section is presented in Supporting Report, Appendix A.

6.4.3 Assessment of riverbed variation based on cross section

The riverbed variation from the river mouth to the Pelaez Bridge is assessed comparing with the results of cross section surveys conducted in November and 2013. Between these survey periods, TY Pablo hit the area. The trend of riverbed variation in this stretch in this period is presented in the table below:

Table 6.4.3 Trend of Riverbed Variation from 2012 to 2013 in the Downstream of the Cagayan de Oro River

Sta. No.	Date	Remarks
Sta.0+500～3+000	2012→2013	Aggradation of riverbed
Sta.3+500	2012→2013	Change of river cross section due to construction of Borja Bridge
Sta.4+000～4+800	2012→2013	Degradation of riverbed Possibility of local scouring at Ysalina and Kagay-An Bridges
Sta.5+500～7+500	2012→2013	Degradation of riverbed
Sta.8+000～10+000	2012→2013	Minor change (almost stable)

- In the downstream of the river from Sta.0+500 to Sta.3+500, the riverbed aggradation is observed. This is corresponded to the result of interview to the local residents and sand mining operators.
- At Ysalina and Kagay-An Bridges, local scouring might be happened surrounding area of the piers at the time of TY Pablo.

- The riverbed variation in the downstream is affected by the sand mining activities in this area. DPWH Region 10 is conducting minor dredging works in this area, and the dredged materials are disposed onto the spoil bank yard located at left bank of the river mouth. The disposed volume is roughly estimated at around 60,000 -90,000m^3 (2-3 ha x 3 m in height). According to DPWH Regional X office, total volume of the dredging works was about 75,000 m^3 for three months from September to November, 2012 and they intermittently continue dredging due to budget constraint.

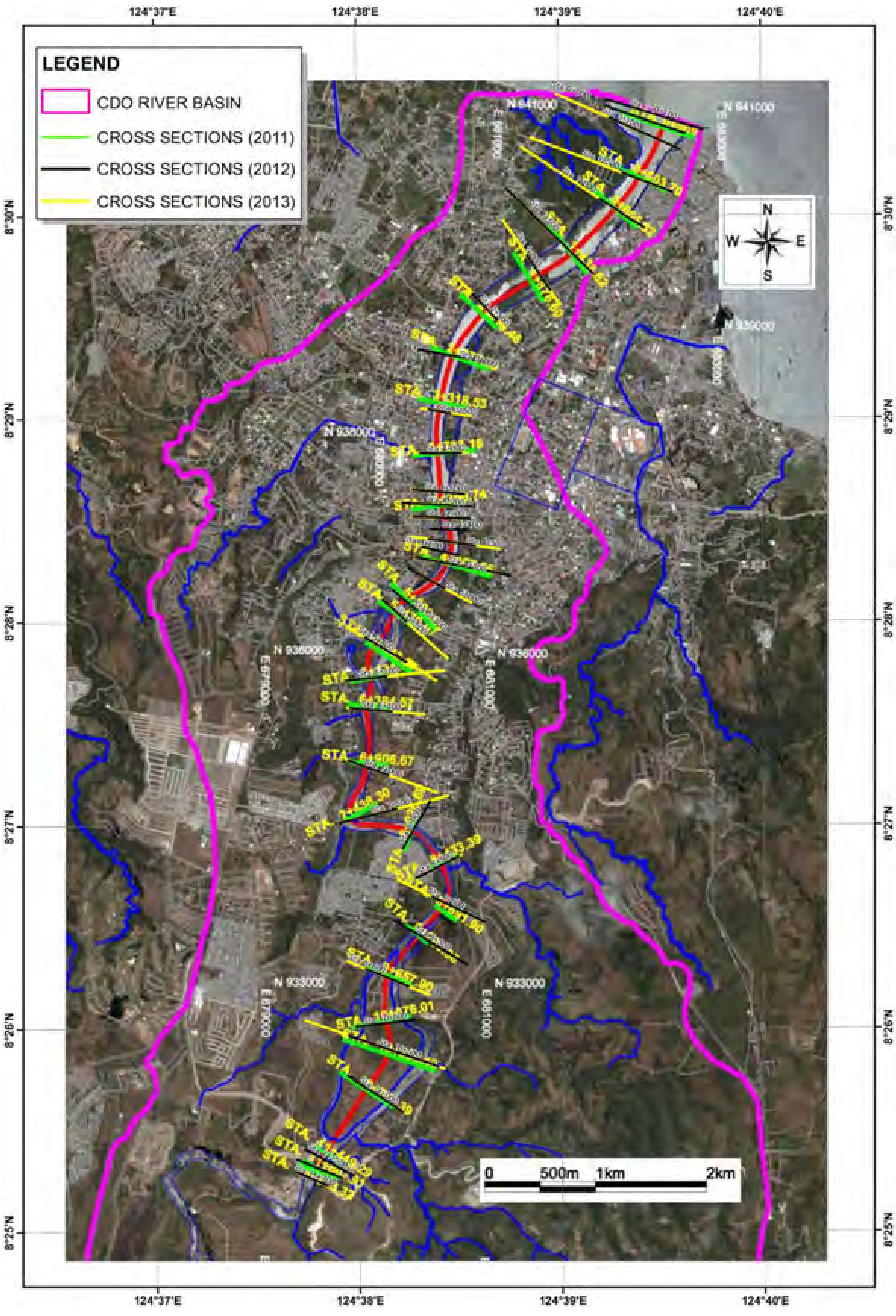


Figure 6.4.3 Location Map of Cross Section Surveys in 2011, 2012 and 2013

6.4.4 Assessment of riverbed variation based on longitudinal section

Longitudinal profiles of the river channel are generated based on the river cross survey data in 2011, 2012 and 2013 mentioned in the above. They are superimposed each other to asses historical variation of riverbed profile in the Cagayan de Oro River. The longitudinal profile is presented in figure in the next page.

Table 6.4.4 Trend of Riverbed Variation from 2011 to 2013 in the Downstream of the Cagayan de Oro River

Sta. No.	Historical change	Remarks
Sta.0+000～1+500	2011-2013	● Average riverbed level is almost stable ● Lowest riverbed profile shows degradation in the downstream stretch. This is considered due to DPWH dredging works.
Sta.0+500～3+000	2011-2013	● 2011→2012 riverbed degradation by 0.5-1.0 m ● 2012→2013 riverbed aggradation by about 0.5 m ● At Maharika Bridge (Sta.2+800) from 2011to 2012, the lowest riverbed was lowered by about 2m. It is considered due to local scouring.
Sta.3+000～5+000	2011-2013	● 2011→2012 riverbed degradation by about 0.5 m ● 2012→2013 Almost stable ● Lowest riverbed level at Sta4+000 from 2012 to 2013 was lowered by about 2 m. This is caused by excavation of riverbed materials undertaken by the on-going construction of the Borja Bridge
Sta.5+000～9+000	2011-2013	● Average riverbed profile from 2011 to 2012 shows local degradations. These are caused by sand mining activities, and considered by local scouring over sandbars and flood plains during Sendong. ● Lowest riverbed profile in the stretch from Sta.7+500-9+000 shows large riverbed degradation from 2012 to 2013. This is caused by active sand mining works in Calacala area.
Sta.9+000～11+600	2012→2013	● Average riverbed level is almost stable ● Riverbed profile in the stretch from Sta.9+000-10+000 shows large riverbed degradation from 2012 to 2013. This is caused by active sand mining works in Calacala area.

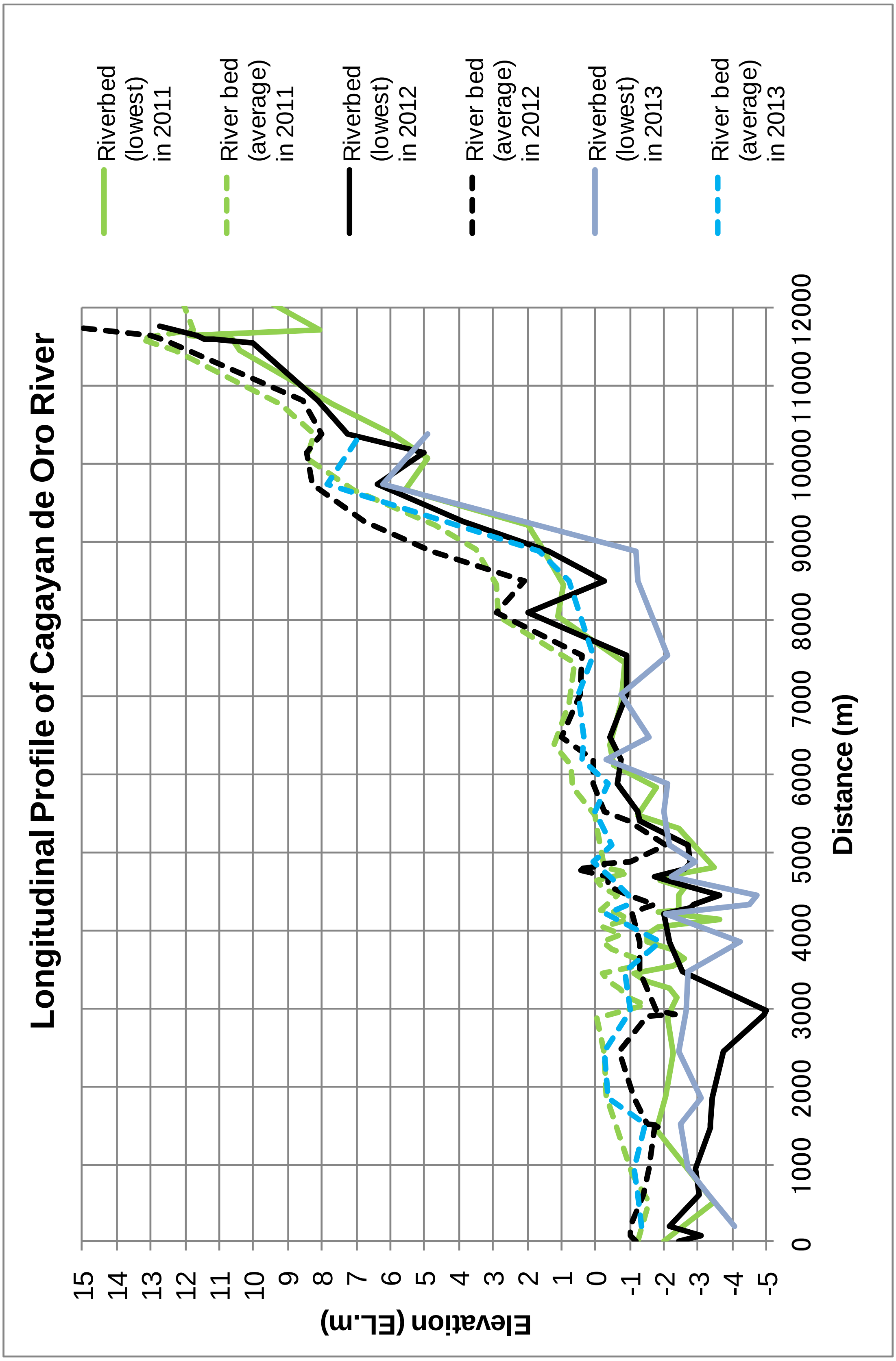


Figure 6.4.4 Comparison of Longitudinal Riverbed Profile in 2011, 2012 and 2013

6.4.5 Characteristics of Riverbed Variation in Cagayan de Oro River

As the result of comparison of cross sections, there is a tendency of riverbed degradation in the downstream stretch from Sta.0+000 – Sta.5+000 from 2011 to 2012. It is considered that it have been caused by a large scale of flushing of riverbed materials during TS Sendong flood with about 50 year return period.

On the other hand, from 2012 to 2013 the riverbed was aggregated in this stretch. Between these periods, though a flood of TY Pablo occurred resulting minor flushing of the riverbed materials, continuous sediment deposition might have been surplus than the flushing by Pablo. The trend of riverbed aggradation is corresponding with the result of hearing about sedimentation in the downstream stretch. Sediment deposition volume in the stretch from Sta.0+000 to Sta.5+000 from 2012 to 2013 is preliminary estimated at around 162,000 m^3 as per comparison of the cross section data.

6.4.6 Study for deepening of river channel in the downstream of the river

The channel excavation/dredging is one of the measures to increase flow capacity of the channel. The case study to evaluate impact of deepening of river channel from Sta.0+000 to Sta.5+000 is conducted for following four (4) cases of deepening up to i) target riverbed level and ii) -50 cm, iii) -100cm, and iv)-200 cm of the target riverbed level.

The water level calculation was conducted under the conditions of the design discharge of 3,400 m^3/s adopting the cross section data of 2012. The simulated water levels at the Kauswagan and Maharila Bridges is presented in figure below. In case of the deepening of river channel by 200 cm, the water level can be lowered by around 50 cm comparing with the present condition.

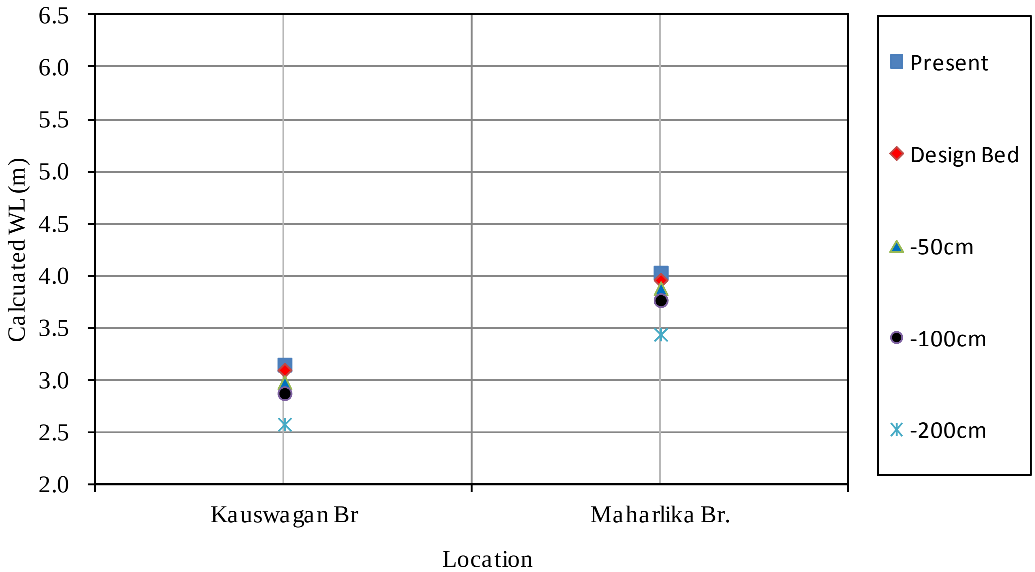


Figure 6.4.5 Relation between Water Level and Deepening of River Channel

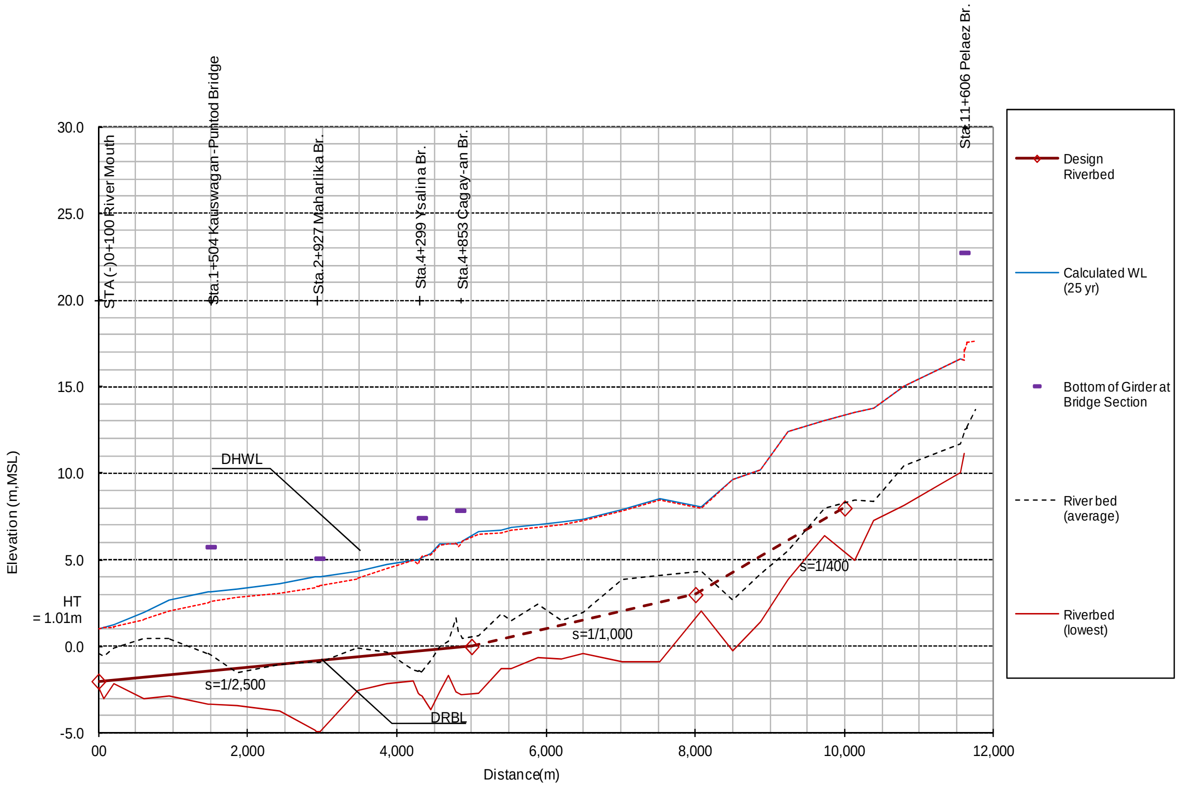


Figure 6.4.6 Case Study for Deepening of Riverbed (Case iv: Deepening by 200cm)

In order to preliminary assess economical viability of the channel dredging, the unit cost of the dredging is compared with that of dike heightening. While the unit price of the dredging in this stretch for case iv which can reduce the water level by 50cm is preliminary estimated at PHP 130,000/m, the unit price of the dike heightening by 50 cm is roughly computed at PHP 9,900/m. The dredging cost would be significantly high comparing with cost for the dike heightening. It is considered that the dredging is not economical measure in the downstream stretch of the Cagayan de Oro River. In addition, it would be difficult to maintain the deeply dredged sections due to sediment transportations from the upstream basin and coastal areas.

6.4.7 Study for removal of sandbars in the downstream of the river

The case study to evaluate the impact of removal of a large sandbar at Sta.2+000 in the downstream of the river was conducted. As the result, it was tuned out that the removal of the sandbar can decrease flood water level in the upstream stretch by around 10 cm. However, the removal of sandbar would affect natural environmental conditions in and surrounding area of the sandbar. Taking into consideration of the above, the removal of the sandbar is not recommended ant it will remain as it is.

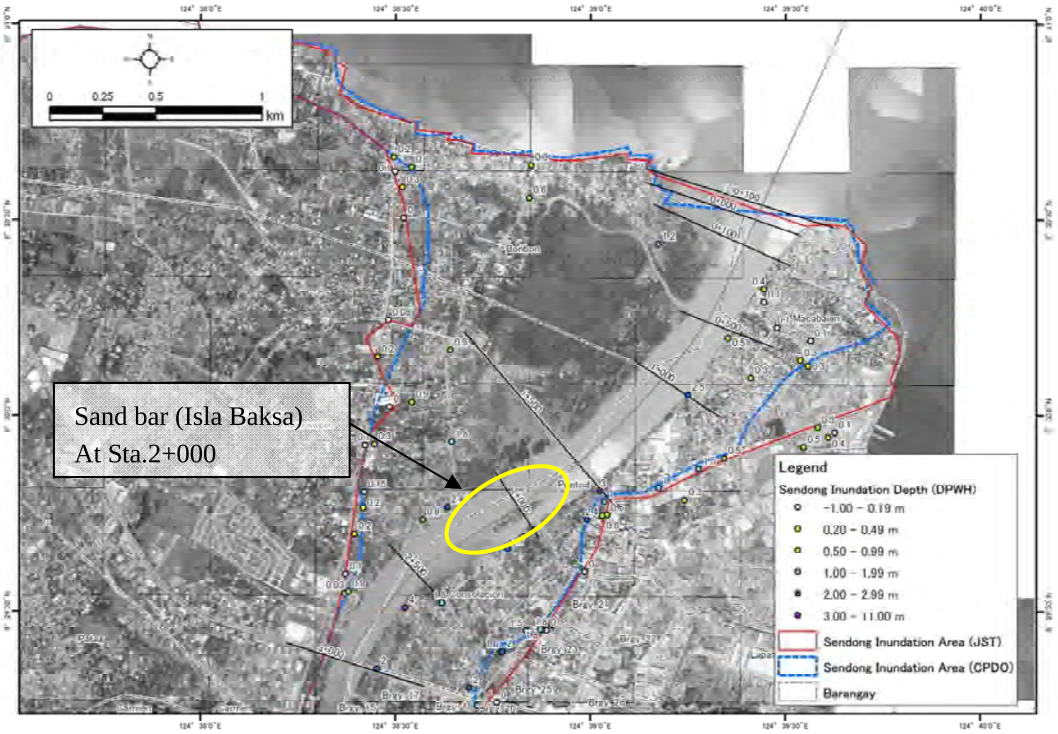


Figure 6.4.7 Location of Sandbar in Sta.2+000

6.4.8 Necessity of periodical maintenance dredging in the downstream river and river mouth

As mentioned above, deepening of channel in the downstream river is not recommendable option. However, siltation in the downstream of the river is a trend of the Cagayan de Oro River. Visible sediment depositions occur over the river mouth and in downstream of the river. Instead of deepening of the river channel, periodic monitoring of channel cross section is proposed and regular maintenance dredging/channel excavation is recommended as a supporting measure to remove sediment deposition.

6.5 Riverbed Fluctuation Analysis

(1) General

Riverbed fluctuation analysis model is preliminary set up aiming at simulating riverbed movement in the downstream stretch from the river mouth to the Pelaez Bridge.

(2) Theoretical Basis

The HEC-RAS 1-D hydraulic model is employed for riverbed fluctuation analysis as the same as the inundation analysis as mentioned in the above.

The sediment continuity equation used in HEC-RAS is known as the Exner equation expressed as

$$(1-\lambda_p)B\frac{\partial \eta}{\partial t} = -\frac{\partial Q_s}{\partial x}$$

where:

	B	=	channel width, m
	η	=	channel elevation, m
	λ_p	=	active layer porosity, -
	t	=	time, sec
	x	=	distance, m
	Q_s	=	transported sediment load, m^3/s

The sediment transport capacity and the sediment supply at the control volume of each section is compared to determine whether a surplus or deficit exists in the control volume. A surplus will mean deposition of sediment while a deficit will mean erosion of the river bed to satisfy the transport capacity.

The sediment transport capacity is computed using mostly empirical equations obtained from laboratory flume experiments. The description of particle motion under the action of flow is largely empirical because the relation between flow and sediment transport has limited theoretical basis. Hence, predictions of sediment load or transport and river bed movement using the various equations will not be very accurate and it is not uncommon for predictions to vary by one or two orders of magnitude.

(3) Sediment Grain Size Analysis

The input data for the sediment discharge computation are the water properties (e.g. temperature, unit weight, kinematic viscosity etc) and sediment properties such as D_n, (n = 10%, 35%, 50%, 65% or 90%) and specific gravity which usually is in the range of 2.5 to 2.7. The particle diameter values are obtained from the particle grain size analysis that was undertaken for the CDO River at specific locations of the reach in this Survey. Location map of riverbed material surveys and result of the grain size analysis are shown in figures Appendix B.

(4) Sediment Load from Upstream Basin

Periodical sampling of suspended sediment is conducted at the Cabula Bridge for 12 years from 2001 to 2012. In addition that, there are four (4) sampling sites (Cabulig, Alubijid, Iponan and Damilag) in surrounding area of the Cagayan de Oro River basin. Location map of these sampling sites of suspended sediment is presented in figure below.

Figure 6.5.1 Location Map of Suspended Sediment Sampling in Region X

Sediment rating curve (relation between discharge and suspended sediment load) were created to preliminary estimate the sediment load from the upstream basin referring to the data of three stations, Cabura, Albujid and Damilag those have more available data in the past record. The rating curve is presented in Figure 6.5.2.

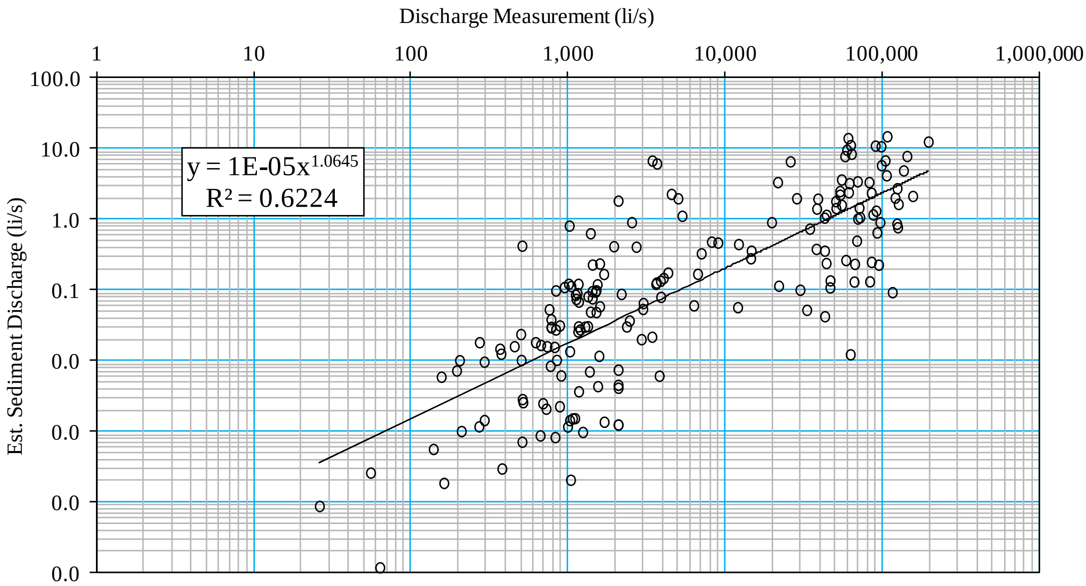


Figure 6.5.2 Relation between Discharge and Suspended Sediment Load (3 sites)

(5) Boundary Condition of Discharge

The boundary condition of discharge is given at the Pelaez Bridge. Long term discharge data at the Cabula Bridge is properly recorded from 1991 to 2012 which is calculated from the water level observation data adopting discharge rating curve. The discharge at the Pelaez Bridge can be estimated based on the specific discharge of the Pelaez Bridge.

(6) Other Conditions

Other conditions for the riverbed fluctuation analysis are same as the inundation analysis as mentioned in the previous section.

(7) Calibration

Existing river cross section survey data of 2012 and 2013 are referred to a calibration of the riverbed fluctuation analysis model. A dry run for the calibration was conducted adopting daily discharge data from 2012 and 2013 for the boundary condition. The result of dry run is presented in the figure below.

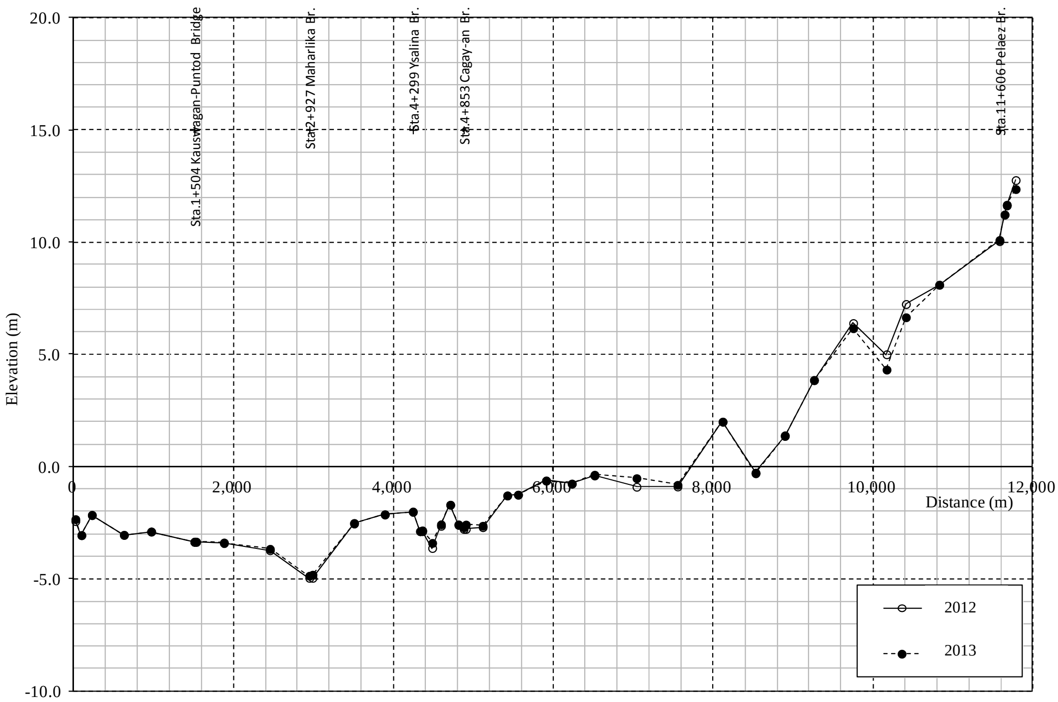


Figure 6.5.3 Simulated Riverbed Profile (2012 – 2013)

The simulated riverbed profile is almost stable in this period and minor scouring is observed at the Maharika and Ysalina Bridge sections and Sta.10+500 while riverbed aggradation is occurred in Sta.7+000. The result of the dry run could not simulate the actual sediment deposition in the downstream stretch as shown in the comparison of existing river cross section data mentioned in the previous sub-section and is not consistence with the actual trend of riverbed fluctuation. One of the reasons of inconsistency is quality and quantity of sampling data of the suspended sediment. The riverbed fluctuation analysis is very sensitive on input condition of the sediment discharge given at the upstream boundary. Due to lack of data for suspended sediment during floods, all discharge data at the time of sampling is less than 200 m^3/s. Hence, it is considered that sediment discharge and grain size distribution of the suspended sediment are not estimated exactly.

Annual sediment discharge from the upstream basin is preliminary estimated by using the said sediment rating curve and available discharge data from 1991 to 2012. It is estimated at about 260,000 m^3/year. On the other hand, annual sediment yield in the Cagayan de Oro River basin can be roughly estimated at 1,300,000 – 2,700,000 m^3/year. It is considered that the sediment discharge derived from the sediment rating curve is underestimated due to constrain of accuracy of the sediment rating curve. In order to improve the riverbed fluctuation analysis model in the Cagayan de Oro River, it is recommended to continue suspended sediment sampling particularly during floods and to conduct periodical river cross section survey to monitor actual riverbed fluctuation.