SUPPORTING REPORT

ON

HYDROLOGY

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1. GENERAL

Hydrological studies were carried out in the following three (3) stages:

(1) Inventory Study (January 1993 - February 1993)

Collection and compilation of meteo-hydrological data of representative medium and small scale river basins in and around the 13 urban centers.

(2) Master Plan Study (March 1993 - July 1993)

Hydraulic and hydrological analyses consisting of the following three (3) components in the Master Plan Study.

- Rainfall and Runoff Analysis
- Preparation of Runoff Model and Probable Flood

(3) Feasibility Study (May 1994 - September 1994)

Runoff simulations using data recorded at the new rainfall and water level stations installed in the Master Plan Study.

The study area for the Master Plan has been designated through the Inventory Study to cover four (4) urban centers or cities; namely, Iloilo, Cebu, Ormoc and Tacloban, as tabulated below.

Item No.	UrbanCenter	Related River	CatchmentArea (km^2)
1.	**Iloilo**	Jaro	412.0
		Iloilo	106.0
2.	**Cebu**	Bulacao	10.7
		Kinalumsan	17.8
		Guadalupe	16.3
		Lahug	6.3
		Subang Duku	12.6
3.	**Ormoc**	Anilao	25.2
		Malbasag	11.1
4.	**Tacloban***	Abucay	2.4
		Mangonbagon	4.9
		Burayan	6.5
Total			631.8

*: Three rivers in Tacloban City are defined as urban drainage channels.

2. CLIMATE AND HYDROLOGY

2.1 Climatic Conditions

The four cities are located in Regions VI, VII and VIII in the Visayas. The climatic conditions of the respective cities are different from each other due to the existence of various plateaus and islands that differ in relief. As the climatic classification map of the Philippines shows (refer to Fig. 2.1), the four cities fall under four (4) different climate types, as described below.

(1) Iloilo

Iloilo City, and the Jaro and Iloilo river basins fall under the Type I climate which has two pronounced seasons, dry from November to April and wet during the rest of the year. The mean annual temperature in Iloilo City is 27.6°C, and the highest monthly temperature is 33.1°C occurring from April to May, while the lowest monthly temperature is 22.7°C which prevails in January and February. The mean annual relative humidity is about 81%.

The climatological normals and extremes in Iloilo City are summarized in Tables 2.1 and 2.2, in accordance with the data of PAGASA.

(2) Cebu

Cebu City and the five related river basins fall under the Type IV climate. This is characterized by a rainfall which is more or less evenly distributed throughout the year. The mean annual temperature in Cebu City is 28.1°C, and the highest monthly temperature is 33.0°C occurring in May, while the lowest monthly temperature is 23.7°C which prevails in February. The mean annual relative humidity is about 79%.

The climatological normals and extremes in Cebu City (Mactan Airport) are summarized in Tables 2.3 and 2.4.

(3) Ormoc

Ormoc City, and Anilao and Malbasag river basins fall under the Type IV climate which is characterized by a more or less even distribution of rainfall throughout the year. No climatic station of PAGASA is located in Ormoc City. There are four (4) stations located near Ormoc City, which have recorded temperature and humidity in and around the Geothermal Power Plant PNOC-EDC (Philippine National Oil Company-Energy Development Corporation) in Tongonan. Although meteorological data are not complete, it is estimated that the highest temperature takes place in May at 29.8°C and the lowest in January at 25.2°C as average from 1984 to 1987. The mean annual relative humidity is about 92%. (Refer to Table 2.5 .)

(4) Tacloban

Tacloban City and its related river basins fall under the Type II climate which exhibits no dry season but a very pronounced heavy rainfall, usually occurring from November to January. The mean annual temperature is 27.2°C, and the highest monthly temperature is 31.4°C occurring in May and August, while the lowest monthly temperature is 22.7°C which prevails in February. The mean annual relative humidity is about 83%.

The climatological normals and extremes in Tacloban City are summarized in Tables 2.6 and 2.7.

2.2 Tropical Cyclones and Rainfall

Tropical Cyclones

In the Visayas, the main factor affecting the climatic condition is tropical cyclone. About 47% of rainfall is associated with tropical cyclones. Tropical cyclones are, by international agreement, classified as follows:

(1)	Tropical Depression (T.D.)	:	with maximum wind speed of up to 63 km/hr.
(2)	Tropical Storm (T.S.)	:	with maximum wind speed between 64 and 118 km/hr.
(3)	Typhoon (T.)	:	with maximum winds greater than 118 km/hr.

During the past 44 years (1948-91), a total of 875 tropical cyclones hit or came close to the Philippine Area of Responsibility (PAR). About 20% of them hit or came close to the Visayas. The number of tropical cyclones which occurred in the PAR is shown in Table 2.8. They occur in October and November, as shown in Fig.2.2. Tracks of cyclones which brought heavy rainfall more than 100 mm in the last decade are presented in Fig. 2.3, and all cyclones affecting the study area and the maximum daily rainfall are shown in Table 2.9.

Rainfall

Rainfall in the study area is as described below.

(1) Available Data

The required rainfall data of the Master Plan study area were obtained from PAGASA and the Water Resources Center, University of San Carlos in Cebu City (WRC-USC). The locations and details of these rainfall stations are given in Table 2.10. Taking into account the location and the period of records, the stations shown in the following table were selected as the representative rainfall stations of the Master Plan study area. The locations of these stations are given in Figs. 2.4 to 2.6.

Item No.	Station Name	Urban Center	Record Period	Location of Station
1.	Iloilo	Iloilo	1961-1991	Airport (PAGASA)
2.	Lahug	Cebu	1949-1991	Airport (PAGASA)
3.	Merida	Ormoc	1971-1991	Synoptic St. (PAGASA)
4.	Tacloban	Tacloban	1961-1991	Airport (PAGASA)

Hourly rainfall records are available only at three (3) stations, Iloilo, Lahug and Tacloban, as shown in the following table.

Item No.	Station	Collected Period
1.	Iloilo City	1961-63, 1972-79, 1981-86
2.	Lahug Airport	1950-56, 1960-65, 1970-74
3.	Tacloban City	1961-81, 1984-88

(2) **Rainfall Characteristics**

Rainfall is probably the most distinctive element of climate in the Philippines. It is very much influenced by the air streams, the typhoons, the Intertropical Convergence Zone and topography.

The average annual rainfall of the Philippines is about 2,530 mm, while in the Visayas, it amounts to about 2,390 mm. The monthly and annual rainfalls at the representative stations are tabulated in Tables 2.11 to 2.14. The average annual rainfall of the four (4) cities are summarized as follows:

City	Rainfall Station	Annual Rainfall (mm)
Iloilo	Iloilo	2,050
Cebu	Lahug	1,630
Ormoc	Merida	2,090
Tacloban	Tacloban	2,280

Generally, heavy rains which may cause flood in the Visayas are usually brought by tropical cyclones from June to December. The mean monthly rainfall in the respective stations also shows seasonal variation of rainfall, as given in Fig. 2.7. Isohyetal maps of annual rainfall indicate areal rainfall distribution of the four cities, as shown in Figs. 2.8 to 2.10.

2.3 River Flow

Available Data

There are a few streamflow gaging stations in the master plan study area and its surrounding areas. The maximum discharge and mean monthly discharge of the related rivers are given in Table 2.15. Daily river discharge records available at 18 stations are listed in Table 2.16, and locations of these stations are given in Figs. 2.4 to 2.6. However, these records are fragmentary and hourly discharges have not been recorded.

Runoff Characteristics

Rainfall characteristics in the study area are described as below.

(1) Iloilo

Based on the streamflow records of rivers in the surrounding areas, the maximum, average and minimum discharges of Iloilo River are estimated as below; the specific base flows of Jaro and Iloilo rivers are estimated to be lower than $0.01 m^3/s/km^2$.

River	Catchment Area (km^2)	Maximum Discharge (m^3/s)	Average Discharge (m^3/s)	Minimum Discharge (m^3/s)
Jalaur-1	1,499	1,625.0	60.5	0.200
Jalaur-2	534	1,937.4	34.0	0.390
Jalaur-3	169	1,003.0	13.1	0.140
Sibalom-1	635	921.0	34.1	0.080
Sibalom-2	619	1,143.3	38.9	0.080
Sibalom-3	117	651.0	4.5	0.030
Sibalom-4	103	357.0	5.7	0.730
Inabasan	97	217.3	1.3	0.000

With distinct rainy and dry seasons, Jaro River is characterized by a regime with poor base flow and comparatively sharp flood peaks. Having rainfall retention in paddy fields, Iloilo River is characterized by a regime with not so sharp flood peaks as Jaro River.

(2) Cebu

Cebu City and the five related river basins are characterized with evenly distributed rainfall throughout the year. Having a prevailing impervious clay loam soil cover, lack of forest cover, steepness of topography, and rather small rainfall, the rivers in Cebu City are characterized by a regime with no sustained base flow and extremely sharp flood peaks.

From the streamflow records of rivers in the surrounding area, the maximum, average and minimum discharge sare estimated as below, and the specific base flows of rivers in Cebu City are estimated to be less than 0.005 $m^3/s/km^2$.

River	Cathment Area (km^2)	Maximum Discharge (m^3/s)	Average Discharge (m^3/s)	Minimum Discharge (m^3/s)
Pitogo	40	37.3	0.50	0.002
Carcar	24	76.7	0.34	0.090
Mananga	64	634.0	0.00	0.000

(3) Ormoc

Anilao and Malbasag river basins in Ormoc City are characterized with evenly distributed rainfall throughout the year. Although the river basins are very steep, the base flows are rather big due to rich springs in the upper stream area. On the other hand, river flood flow is quite fast and sharp as evidenced by the flood on November 5, 1991.

From the streamflow records of rivers in the surrounding area, the maximum, average and minimum discharges are estimated as below, and the specific base flow of Anilao and Malbasag rivers is estimated to be less than 0.01 $m^3/s/km^2$.

River	Catchment Area (km^2)	Maximum Discharge (m^3/s)	Average Discharge (m^3/s)	Minimum Discharge (m^3/s)
Mas-in	22	59.4	1.59	0.015
Baleon	19	53.2	0.99	0.055
Bao	65	167.5	4.75	0.000

(4) Tacloban

The catchment areas of Abucay, Mangonbagon and Burayan rivers are small at less than 10 km and flat with poor vegetation. Therefore, low flows of the rivers are very small, while storm rains usually bring sharp and high flood peaks.

From the streamflow records of rivers in the surrounding area, the maximum, average and minimum discharges are estimated as below, and the specific base flow of rivers in Tacloban City is estimated to be less than 0.02 $m^3/s/km^2$.

River	Catchment Area (km^2)	Maximum Discharge (m^3/s)	Average Discharge (m^3/s)	Minimum Discharge (m^3/s)
Calingcaguing	128	542.5	8.08	0.760
Mainit	98	583.2	7.66	1.400
Lingayon	10	112.6	1.25	0.130
Dap-Dap	30	116.6	1.76	0.050

2.4 Tidal Water Level

According to the Predicted Tide and Current Tables (National Mapping and Resources Information Authority, DENR, 1991) and the results of the topographic survey conducted for the Study, the tidal water levels in the four cities are summarized as follows, and illustrated in Fig. 2.11.

Item No.	Water Level	Iloilo	Cebu	Ormoc	Tacloban
1.	Mean Spring Higher High Water (MSHHW)	+1.82m	+1.75m	+1.95m	-.-
2.	Mean Higher High Water (MHHW)	+1.57m	+1.47m	+1.66m	+0.69m
3.	Mean High Water (MHW)	+1.30m	+1.19m	+1.39m	+0.51m
4.	Mean Sea Level (MSL)	+0.75m	+0.69m	+0.80m	+0.29m
5.	Mean Low Water (MLW)	+0.21m	+0.18m	+0.20m	+0.04m

Note: Ormoc is a secondary tide station; the others are primary tide stations. Except Tacloban, datum planes of Iloilo and Cebu are set up from 19 years series of actual observations. Datum plane of Ormoc is from one month actual observation.

3. EROSION AND SEDIMENTATION

3.1 Present Sediment Condition

Through the field investigation and data collection, sediment condition in the four cities has been observed. Generally, erosion and sedimentation have not become a serious issue in flooding problems of the study area.

(1) Iloilo

Along Jaro River and its main tributary, Aganan River, there are not observed heavy channel erosions and bank scouring. Vegetation cover in the upper stream area is thick, stabilizing the surface soil layer in the river basin.

On the other hand, degradation of the riverbed occurs more often in the middle to lower reaches. Most of the bridge footings have exposed, even concrete piles under the footing are observed above the riverbed, endangering bridge structures. Reinforcement works have been provided for the foundations of Montinola and Jaro bridges. This rapid riverbed degradation has been caused by the imbalance of sediment due to collection of riverbed materials for concrete aggregates.

For Iloilo River, dredging works are undertaken by the Philippine Ports Authority (PPA) for approx. 3 km from the river mouth every year to ensure inland navigation. Iloilo River has become shallower due to sediment brought by tributaries such as the Mandurriao River (Pandan Creek), Carahaunan Creek and Baunan River, which flow through agricultural land. However, sediment deposit in the river channel of Iloilo is estimated to be small, because the dredging works are executed for only one month with a dredging volume of 300 to 400 m^3.

(2) Cebu

The five rivers in Cebu City are mostly steep in the upper-middle reaches and gentle in the lower reaches. Although urbanization has extended to the middle reaches, serious sedimentation is not observed along the channel, while all rivers have suffered river mouth clogging by sediment mixed with solid wastes.

Generally, the upper watershed of rivers are covered by thin vegetation of bushes and grasses except that of Buhisan Dam (Kinalumsan River) where the city government has promoted a reforestation program. Due to the small rainfall, the rivers have neither experienced heavy sedimentation nor debris flows.

Subdivisions have been constructed mostly in the middle-upper reaches of the rivers except Lahug River. Since no protection works have been provided in the subdivisions, not only the developed area but also the urban areas in the lower reaches are under the menace of sediment damage.

A study on sedimentation was carried out for Mananga River which is located adjacent to Bulacao River (Sediment Transport Study: Cebu Water Supply Project, 1991). In this report, the annual total sediment yield in the proposed Mananga Dam watershed (69.3 km^2) was estimated at 254,800 m^3/year, of which the bed load component is assumed to be 29.6%.

(3) Ormoc

Both Anilao and Malbasag rivers are generally steep from 1/150 to 1/35 at the lower to middle reaches. Therefore, river flows are fast having a big erodible energy.

Although vegetations in the middle and upper reaches are thick, there are some portions observed sliding in the steep valley.

Most of the river basins are covered by plantations of coconut and sugarcane, and trees. Sheet and gully erosions are considered to be small, while some small areas are denuded due to the shifting cultivation still being engaged in mountainous areas of Leyte.

During Typhoon Uring, a flush flood scoured many spots along the river bank, pulling out trees, carrying boulders and sweeping houses and bridges. Sediment was deposited mainly in the lower reaches, which was braided from the river banks in the deep valley. No big accumulation of sediment was reported in the middle and upper reaches of rivers.

(4) Tacloban

Due to the river topography that is quite gentle and flat, no sediment is observed in the river channel. Only solid wastes dumped in the channel are found.

3.2 Estimation of Sediment Yield

Considering the geological conditions which are almost tertiary and/or quaternary strata in the study area, Murano's Formula is applied to the estimation of specific sediment yield. This formula can provide high correlations for several geological conditions and is given as follows:

$$Log\ qs = a + b \log A + c \log R + d \log ME + e \log Rr$$

where;

qs	:	specific sediment yield (m^3/year/km^2)
A	:	catchment area (km^2)
R	:	annual mean rainfall (mm)
ME	:	mean elevation of watershed (m)
Rr	:	relief ratio
a...e	:	coefficient depending on geology for each term determined by multiple regression analysis, as tabulated in the following table:

Geology	*a*	*b*	*c*	*d*	*e*	Correlation Coefficient
I	-8.5498	-0.3926	1.3380	0.2523	0.0955	0.6669
III	-2.7844	-0.0618	2.0970	0.1071	1.8900	0.8342
IV	-2.9090	-0.3928	0.9728	0.9631	-0.2270	0.6059

where;

I	:	watershed comprising old sedimentation rocks (Paleozoic and Mesozoic strata)
III	:	watershed mainly comprising new sedimentary rocks (Tertiary and Quaternary strata and volcanic detritus)
IV	:	watershed mainly comprising eruptive rocks (andesite, liparite)

With respect to the adaptability of sediment yield to be estimated using this formula, the trial calculation with Jalaur river basin in Panay is made, as shown in Table 3.1. According to the results, considerably reliable values of sediment yield can be obtained for these watersheds, though it may be problematic to determine the other various characteristic watersheds. A summary of specific sediment yield is given below.

City Name	River Name	Specific Sediment Yield (m^3/year/km^2)
Iloilo	Iloilo	8.0
	Jaro	323.0
Cebu	Bulacao	782.0
	Kinalumsan	307.0
	Guadalupe	451.0
	Lahug	255.0
	Subang Daku	187.0
Ormoc	Anilao	1,655.0
	Malbasag	2,855.0
Tacloban	Burayan	0.4
	Mangonbangon	2.0
	Abucay	18.0

Judging from the computed specific sediment yield, some sediment and erosion control works are required for the two rivers in Ormoc City.

4. RAINFALL ANALYSIS

4.1 Probable Maximum Daily Rainfall

The recorded maximum rainfalls of 1-day, 2-day and 3-day duration at the stations are shown in Tables 4.1 to 4.4. Probable maximum daily rainfalls have been computed by the Iwai, Thomas, Hazen, Ishihara-Takase and Gumbel methods. Results of analysis are shown in Tables 4.5 to 4.8. Results of the Iwai Method are summarized below:

(Unit: mm/day)

Return Period	Iloilo	Cebu Lahug	Ormoc Merida	Tacloban
2	121.1	91.4	130.7	119.9
5	159.6	123.5	184.7	146.1
10	191.7	145.7	221.7	161.2
20	227.3	167.5	259.1	174.5
50	280.7	196.7	309.5	190.2
100	326.7	219.4	349.0	201.3

4.2 Rainfall Intensity and Duration

Rainfall intensity-duration-frequency data of the Philippines were prepared by the Hydrology and Flood Forecasting Center of PAGASA in 1981. The detailed data of related stations (Iloilo, Cebu and Tacloban) are shown in Table 4.9. Intensity of computed extreme values of a 100-year return period are shown in the following table:

(Unit: mm/hr)

Stations	10 min	1 hr	2 hrs	6 hrs	24 hrs
Iloilo	232.2	96.1	62.8	31.3	14.7
Cebu	229.2	113.3	84.9	41.0	12.7
Tacloban	165.6	74.7	50.5	25.9	13.1

Intensity-duration curves can be put into an equation of the following form in comparison with other formulas such as the Sherman Formula and the Kuno-Ishiguro Formula. (Refer to Table 4.10.)

$$I = b / (t+a) \qquad \textit{(Talbot Formula)}$$

where;

- I : rainfall intensity (mm/hr)
- t : storm duration (min.)
- a, b : regression constants to be derived by analytical method employing the least square method.

The results of analysis are as follows:

Return Period	Iloilo		Cebu		Tacloban	
	a	*b*	*a*	*b*	*a*	*b*
2	39	5,320	31	4,866	34	4,839
5	47	7,738	44	7,975	44	6,762
10	50	9,350	50	10,094	49	8,048
20	53	10,930	54	12,103	53	9,281
50	56	12,904	59	14,808	57	10,917
100	57	14,410	62	16,799	60	12,127

As for Ormoc City, neither hourly rainfall data nor intensity-duration analysis is available. Therefore, the intensity-duration curve of Tacloban is adopted. The probable daily rainfall in Ormoc is analyzed by correlation between the Merida and PNOC-EDC stations. The probable daily rainfall of Merida Station is adopted by means of the Iwai Method.

$$Ror = 2.008\, Rmr + 50.0$$

where,

Ror	:	daily rainfall in Ormoc (mm/day)
Rmr	:	daily rainfall in Merida (mm/day)

Rainfall intensity chart by the said rainfall intensity formula are shown in Fig. 4.1 to 4.3.

4.3 Design Hyetograph

Storm Rainfall Duration

The duration of storm rainfall is an important factor to set up the design hyetograph. It has been justified from the rainfall mass curves prepared based on hourly rainfall records of big storms, as presented in Fig. 4.4, that most of storm rainfalls, excluding some exceptional cases, ceased within 24 hours. On the other hand, the lag time of flood duration has been estimated at about 20 hours in the longest watercourse of Jaro River. Thus, the storm rainfall duration is fixed at 24 hours. The design hydrographs of the four cities, Iloilo, Cebu, Tacloban and Ormoc, are constructed by using the intensity-duration-frequency equation of PAGASA for its hourly distribution and the Iwai Method for its probable daily rainfall, as illustrated in Fig. 4.5 to 4.8.

Basin Mean Probable Rainfall (R_m)

The basin mean rainfall is estimated by the area conversion factor together with the adjustment coefficient of altitude.

$$R_m = f \cdot R_0$$

where;

R_m	:	basin mean probable rainfall
R_0	:	point rainfall

f	:	conversion factor		
		$f = f_a \cdot f_e$		
		where; f_a	:	area conversion factor
		f_e	:	altitude adjustment factor

(1) Areal Conversion Factor (f_a)

Basin mean probable rainfalls are computed from the hyetograph of point rainfall at the representative station. This probable point rainfall is converted into area rainfall for the flood runoff analyses. Since there is no sufficient data to obtain the area rainfall of each river basin, Horton's formula, which has been applied to both the Panay river basin in Panay Island and the Ilog-Hilabangan river basin in Negros Island, area rainfall is examined by the rainfall data in or around Cebu City.

The formula is expressed as follows:

$$P = P_0 \cdot EXP \cdot \left[-0.1 \cdot (0.386 \cdot A)^{0.31}\right]$$

$$fa = P/P_0$$

where;

fa : area conversion factor
P : area rainfall (mm)
P_0 : point rainfall (mm)
A : area (km^2)

Isohyetal maps of storm rainfalls observed in Cebu City in 1978 are prepared as shown in Fig. 4.9, and the ratio (P/P_o) of areal rainfall to point rainfall and catchment areas (A) are computed. The ratio and catchment area plotted in Fig. 4.10.

(2) Altitude Adjustment Factor (f_e)

Since the representative stations are usually located in rather low areas with altitudes ranging from El. 10 m to El. 40 m, the rainfall amount is adjusted by altitude for the rainfall in mountain areas. Totally, 12 rainfall stations in and around Cebu City were examined to estimate the relation of rainfall to altitude.

Mean annual rainfalls for 11 years from 1981 to 1991 were calculated for 12 stations located at various elevations from El. 8 m to El. 780 m. As shown in Fig. 4.11, rainfall-altitude has a high correlation, since the altitude is lower than 400 m, with the formula expressed as below:

$$f_e = P / P_0 = EXP\,[\,h / 1{,}480\,]$$

where;

f_e : altitude adjustment factor
h : altitude (m)
P : area rainfall
P_0 : point rainfall

(3) Conversion Factor (f)

Taking the above-mentioned study into account, basin mean probable rainfall is estimated using the following area conversion factor.

City	River	Catchment Area at Base Point (km^2)	Altitude of Representative Rainfall Station (m)	Mean Altitude of River Basin (m)	f_a	f_e	Conversion Factor (f)
Iloilo	Jaro	412.1	10	190	0.62	1.0	0.62
	Iloilo	93.1	10	20	0.74	1.0	0.74
Cebu	Bulacao	10.7	40	400	0.86	1.3	1.12
	Kinalumsan	17.8	40	180	0.83	1.1	0.91
	Gudalupe	16.3	40	320	0.84	1.2	1.01
	Lahug	6.3	40	220	0.88	1.2	1.06
	Subang Daku	12.6	40	60	0.85	1.0	0.85
Ormoc	Anilao	25.2	400	250	0.82	0.83	0.72
	Malbasag	11.1	400	200	0.85	0.87	0.74

Rainfall Distribution Pattern

The hourly rainfall distribution is assumed to have a center-concentrated pattern which is commonly applied to the estimation of design flood runoff. This pattern is derived from the rainfall intensity-duration curve using the actual hourly data of the related station.

5. FLOOD RUNOFF ANALYSIS

5.1 River System Model

The river system model is constructed for the flood runoff analysis of different river basins in their shapes, stream networks and topographies. The model comprises all the elements of a river system such as subbasins and channels. These elements are linked together by computation points. A base point is the principal point among computation points to evaluate the design flood discharge for the formulation of a flood control plan.

In constructing the river system model, a river basin is firstly divided into several sub-basins. River channels connecting the subbasins are set up together with computation points, and the computation point is designated to be located at:

(1) the Junction of mainstream with major tributaries;

(2) the existing streamflow gaging station;

(3) the river section bounding catchments with different runoff characteristics; and

(4) the existing and proposed river structure sites.

Subbasin areas of the nine (9) rivers are shown in Table 5.1. The basin divisions including all basin components and river system model of the related rivers are shown in Fig. 5.1 to 5.8.

The base point for each river is placed at the following location:

City	River	Location of Base Point	Catchment Area (km^2)
Iloilo	Jaro	Confluence with Aganan River	412.1
	Iloilo	Confluence with Carahaunan Brook	93.1
Cebu	Bulacao	Barangay Bulacao (500 m upstream of Rizal Ave.)	10.7
	Kinalumsan	Confluence with Linao River	17.8
	Guadalupe	Barangay Guadalupe (500 m upstream of M. Velez Br.)	16.3
	Lahug	Camputhaw Br.	6.3
	Subang Daku	St. Lucia Subdivision	12.6
Ormoc	Anilao	4 km upstream of estuary	
	Malbasag	2 km upstream of estuary	11.1

5.2 Methodology

Unit Hydrograph Method is employed for the flood runoff computation in the study area on account of the following reasons:

(1) The river basins in the Master Plan area are generally small, although the basins are to be divided into several subbasins with an area of a few square kilometers due to their land use conditions.

(2) No hydrological station is provided; hence, there is hardly any flood records for runoff computation by other runoff models requiring many parameters.

(3) Flood hydrograph is required to study some alternatives of flood control plans such as dams, retarding basin, etc.

Therefore, the river runoff computation has been carried out by the unit hydrograph derived from Nakayasu's Synthetic Unit Hydrograph Method, while flood routing along the Jaro and Iloilo rivers has been calculated by the storage function method, because these rivers are relatively wider and longer resulting in effects of channel storage and retarding.

(1) Nakayasu's Unit Hydrograph

Values of the unit hydrograph are divided into three categories by its shape: These are the maximum discharge (Q_{max}), discharge at the time of rising limb (Q_a) and discharge of falling limb (Q_d). The discharge at each category is calculated by the following formula.

Maximum discharge:

$$Q_{max} = \frac{1}{3.6} \cdot A \cdot R_0 / (0.3 \cdot T_1 + T_{0.3})$$

Discharge for rising unit hydrograph:

$$0 \le t \le T_1 \rightarrow \frac{Q_a}{Q_{max}} = \left(\frac{t}{T_1}\right)^{2.4}$$

Discharge for falling unit hydrograph

$$1 \ge \frac{Q_d}{Q_{max}} \ge 0.3 \rightarrow \frac{Q_d}{Q_{max}} = 0.3^{(t-T)/T_{0.3}}$$

$$0.3 \ge \frac{Q_d}{Q_{max}} \ge 0.3^2 \rightarrow \frac{Q_d}{Q_{max}} = 0.3^{(t-T_1+0.5T_{0.3})/1.5T_{0.3}}$$

$$0.3^2 \ge \frac{Q_d}{Q_{max}} \rightarrow \frac{Q_d}{Q_{max}} = 0.3^{(t-T_1+1.5T_{0.3})/2.0T_{0.3}}$$

where,

Q_{max}	:	maximum discharge of unit hydrograph (m^3/s)
Q_a, Q_d	:	discharge at the time of rising and falling limb of unit hydrograph (m^3/s)
A	:	catchment area (km^2)
R_0	:	unit rainfall (mm)
T_1	:	time from start of runoff to maximum discharge $T_1 = t_g + 0.8tr$

where:

t_g	:	time lag

L<=15km	:	$t_g = 0.21L^{0.7}$
L>15km	:	$t_g = 0.4+0.058L$
tr	:	duration of unit rainfall to be used
$T_{0.3}$	:	time required until the discharge recesses to 0.3 times the maximum discharge; $T_{0.3} = 0.47(A \cdot L)^{0.25}$

(2) Storage Function

To express the nonlinear type characteristics of runoff phenomena, the storage function method can give the process of transformation from rainfall to runoff on the assumption that there is a one-to-one functional relation between the volume of storage and runoff. Calculations of runoff from rainfall are made through the use of volume of storage as the medium function. Through the use of this method, a relationship can be established between the volume of storage (S) of a basin or river channel and discharge (Q) from it. This relationship is expressed as:

$S_1 = K\, Q_1^{p}$ (K, p: constant)

Flood routing in the river channel is performed by the combination of this equation of motion with the following equation of continuity.

$$\frac{dS_1}{dt} = \sum_{j=1}^{n} fj \cdot Ij - Q_1$$

where;

Ij	:	Inflow from the upstream end of a river course to the river channel being considered (m^3/s)
fj	:	Inflow coefficient
$Q_1(t)=Q(t+T_1)$	:	Discharge at the downstream end of basin under the consideration of lag time (m^3/s)
S_1	:	Apparent volume of storage of river channel
T_1	:	Lag time: $T_1 = 7.36 \cdot 10^{(-4)} \cdot L \cdot I^{(-0.5)}$
L	:	Length of watercourse (km)
I	:	Average bed slope of river channel

There is a retarding channel located in the middle stream of Jaro-Tigum River. Although a simple analysis was made to estimate the retarding effect of the channel during the Master Plan Study in 1993, some mathematical analysis was carried out on the basis of the topographical map with a scale of 1/10,000 prepared by JICA in 1994.

The topographic map shows that the lower to middle reaches of Tigum River forms a wide river terrace with a braided pattern for approximately 10 km, and this is known as a retarding channel. The location and inundation area are presented in Fig. 5.9, where the inundation area is delineated by the flood flowing section with a discharge of 1,000 m^3/s.

The cross-sections of river channel and inundation area are shown in Fig. 5.10. The non-uniform analysis and the aforementioned storage function model were applied to estimate the retarding/storage effect on floods. The effect is expressed in the storage function's parameter such as K and p in the above equation. The relation is computed as shown in Fig. 5.11. Applying the parameters to this model, flood discharge is retarded with its peak discharge by about 60%.

5.3 Effective Rainfall

Effective rainfall is estimated on account of saturation rainfall and primary runoff rate. Considering the geological conditions of the study area, saturation rainfall is taken at 100 mm for Iloilo, Cebu and Tacloban, and 300 mm for Ormoc. Furthermore, saturation rainfall of the Iloilo river basin is estimated higher by 50 mm than the Jaro river basin, since the Iloilo river basin mostly consists of paddy fields where rainfall is stored more.

The primary runoff rate employed is generally 0.5, while it is 0.8 in Cebu on account of the highly urbanized land use.

City/River Condition	Iloilo	Cebu	Ormoc	Tacloban
Geology	Non-Quaternary	Non-Quaternary	Quaternary	Non-Quaternary
Primary Runoff Rate	0.5	0.8	0.5	0.5
Saturation Rainfall	100 mm*	100 mm	300 mm	100 mm

* 150mm for Iloilo river basin.

5.4 Lag Time of Channel Flow

Various empirical formulas have been proposed for the estimation of lag time of channel flow. The Kraven formula, the simplest among them, is adopted for this Study. The Kraven formula is expressed as follows, and the results of calculation are shown in Table 5.2.

$$Tc = L/W$$

where;

I	:	slope of watercourse
W	:	flood runoff velocity (m/s)
L	:	length of watercourse (km)

I	over 1/100	1/100 - 1/200	below 1/200
W	3.5 m/s	3.0 m/s	2.1 m/s

5.5 Probable Flood Discharge

Probable flood discharges of the rivers are computed for 2, 5, 10, 20, 50 and 100-year return periods. The probable discharges at respective base points are given below:

(Unit: m^3/s)

City	River	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
Iloilo	Jaro	360	493	696	966	1,391	1,765
	Tigum*	146	204	293	415	616	797
	Aganan*	214	289	403	551	775	968
	Iloilo	190	255	314	390	584	774
	Mandurriao*	36	45	54	63	91	119
Cebu	Bulacao	110	140	164	187	214	236
	Kinalumsan	109	140	162	185	213	235
	Guadalupe	118	153	177	202	233	257
	Lahug	63	80	93	106	121	134
	Subang Daku	107	138	160	181	209	229
Ormoc	Anilao	247	313	362	453	603	719
	Malbasag	129	162	195	250	328	387

The specific discharges of 50-year return period are also estimated as below for comparison with those of other river basins, while the flood discharges are estimated by rounding the computed probable discharges.

City Name	River Name	Basin Area (km^2)	Peak Discharge (m^3/s)	Specific Discharge ($m^3/s/km^2$)
Iloilo	Jaro	412.1	1,400	3.4
	Tigum*	213.3	600	2.8
	Aganan*	198.8	800	4.0
	Iloilo	93.1	600	6.4
	Mandurriao*	9.9	100	10.1
Cebu	Bulacao	10.7	220	20.6
	Kinalumsan	17.8	240	13.5
	Guadalupe	16.3	260	16.0
	Lahug	6.3	140	22.2
	Subang Daku	12.6	230	18.3
Ormoc	Anilao	25.2	610	24.2
	Malbasag	11.1	330	29.7

* Tributaries of the object rivers.

The specific discharges are compared with those estimated for other river basins, as shown in Fig. 5.12. The computed flood discharge is within the range of flood discharge for rivers in the Philippines. Therefore, the method and parameters employed in the computation are justified for rivers in the study area.

5.6 Probable Discharge for Drainage Area

Probable flood discharge for the urban drainage area is computed using the Rational Formula. Maximum flood discharges are given by the following formula:

$$Qp = 0.2778\, f\, r\, A$$

where;

Qp : maximum flood discharge (m^3/s)

f	:	runoff coefficient
R	:	rainfall intensity within the time of flood concentration (mm/hr)
A	:	catchment area (km^2)

Due to scarcity of flood discharge data and the corresponding rainfall records during floods, the runoff coefficient is determined depending on the land use conditions from the table below. Peak discharges of drainage areas in the four cities are shown in Table 5.3.

Land Use in River Basin	Runoff Coefficient
Urban Area-1 (Low Density, Residential)	0.50
Urban Area-2 (Middle Density, Residential)	0.65
Urban Area-3 (High Density, Residential)	0.80
Mountain and Hill of Tertiary	0.70 - 0.80
Rolling Land and Forest	0.50 - 0.75
Basin with Around Half of Flat Land	0.50 - 0.75

Source: Nationwide Flood Control Plan and River Dredging Program (DPWH, 1982)

5.7 Design Hydrograph

Design hydrograph at the base points in the related rivers are shown in Figs. 5.13 to 5.15. The probable flood discharge is estimated for the base point of each river, as shown in Figs. 5.16 to 5.18.

6. RUNOFF SIMULATION WITH NEW HYDROLOGICAL STATIONS

6.1 Data Collection

Data of New Hydrological Stations

Six (6) new automatic hydrological stations were installed in the Study Area of the Master Plan by the JICA Study Team in June, 1993. Additional hydrological data, which were recorded in Iloilo, Cebu and Ormoc Cities from June 1993 to April 1994, were also collected and processed to verify and examine the flood runoff model and parameters employed in the Master Plan Study.

Names of the stations and their observation periods are given in Table 6.1. Data recording in the stations have not been satisfactorily made due to inadequate maintenance. Rainfall was mostly recorded during the rainy season in 1993. Thedaily rainfall records of these stations are shown in Table 6.2. Water levels at flood time were observed only at the Colon Bridge Water Level Gauging Station in Cebu City. The daily maximum water level record is shown in Table 6.3. Those in Iloilo and Ormoc were either suspended or problematic resulting in no available data on flood.

Data of Existing Hydrological Station s

Rainfall data of the existing stations under either PAGASA, USC-WRC or PNOC-EDC were also collected to support the hydrological analysis. Only daily rainfall data were obtained at two (2) stations in Iloilo, four (4) stations in and around Ormoc/Tacloban, and 15 stations in Cebu. Their recording conditions are also presented in Table 6.1.

Flood Events

In 1993, a total of 32 typhoons, tropical depressions or tropical storms passed the Philippine Area of Responsibility. Out of them, 8 typhoon/tropical storms had affected the Visayas Region, as given in Table 6.4

(1) Iloilo City

Daily rainfall exceeding 100 mm observed at either Santa Barbara Station, Iloilo Airport Station or Cabatuan Station are given as below:

(Unit: mm/day)

Item No.	Date	Sta.Barbara	Iloilo Airport	Cabatuan	Remarks
1	93/08/08	54.0	161.2	14.7	T.Openg
2	93/08/21	100.0	51.2	26.7	T.S.Saling
3	93/08/22	82.0	42.8	35.8	T.S.Saling
4	93/12/07	134.0	50.2	79.5	T.Monang
5	93/12/26	n.a.	132.5	116.6	T.Puring
6	94/04/04	117.0	89.0	74.6	T.S.Bising

Note: T.= Typhoon T.S.= Tropical storm n.a.= not available

All storm rainfalls higher than 100 mm were influenced by typhoons or tropical storms. The maximum daily rainfall recorded during the observation period was 134.0 mm on December 7 at Sta. Barbara, 161.2 mm on August 8 at Iloilo Airport, and 116.6 mm on December 26 at Cabatuan. The comparison of daily rainfalls among the three (3) stations show that storm rainfalls are correlated, especially those caused by typhoons, as shown in Fig. 6.1.

The water level record at the Jaro Bridge Gauging Station has not been available since June 15, 1993 due to heavy siltation inside the stilling well. The maximum water level during the observation period occurred on July 9, 1993 in T.S. Huling. DPWH VI Regional Office reported that the maximum flood after the installation of the water gauge occurred from December 26 to 29, 1993 during T. Puring when the water level rose almost to the floor level of the station house.

(2) Ormoc City

Daily rainfall exceeding 100 mm observed at the three (3) rainfall stations, Bagong, Merida and PNOC-EDC, are given below.

(Unit: mm/day)

Item No.	Date	Bagong	Merida	PNOC-EDC	Remarks
1	93/08/21	119.0	61.5	18.1	T.S.Saling
2	93/08/22	162.0	66.4	165.0	T.S.Saling
3	93/09/30	140.0	60.0	4.5	T.Kadiang
4	93/11/20	287.0	82.0	26.0	T.S.Luring
5	93/11/21	0.0	0.0	181.5	T.S.Luring
6	93/12/15	124.0	17.0	18.9	T.D.Oning
7	93/12/20	10.0	3.0	100.0	
8	93/12/22	147.0	14.0	7.5	T.Puring
9	93/12/23	20.0	15.2	117.9	T.Puring
10	93/12/24	56.0	5.2	106.5	T.Puring
11	93/12/27	n.a.	8.0	375.5	T.Puring

These storm rains were also caused by either tropical storms or typhoons. The maximum daily rainfall recorded during the observation period was 287 mm on November 20 at Bagong, 82.0 mm on November 20 at Merida, and 375.5 mm on December 27 at PNOC-EDC.

Correlation of daily rainfall has been examined for the three stations, as drawn in Fig. 6.2. The rainfall at Bagong Station in Anilao river basin is hardly correlated to the two other stations, Merida and PNOC-EDC. Therefore, it is evaluated that storm rainfall area is small, covering a radius of less than 5 km.

It seems that the water level records at Anilao Bridge Gauging Station are not accurate due to the excavation works at the riverbed. This failure in observation or recording may be due to the following facts:

(a) Sand and gravel closed the intake pipe of the station since June 19, 1993.

(b) The rise in water level was observed to be only 30 cm, during T.S. Saling on August 23, 1993, although a flash flood was reported on the same day and rainfall of more than 250 mm was observed for two (2) consecutive days at Bagong Rainfall Station.

(c) No water level change was observed when 287 mm of rainfall was recorded at Bagong Rainfall Station on November 20, 1993.

(3) Cebu City

The daily rainfall exceeding 100 mm observed at either Guadalupe E.C., Mactan or Talamban rainfall stations are given below:

(Unit: mm/day)

Item No.	Date	Guadalupe	Mactan	Talamban	Remarks
1	93/09/08	125.0	9.8	15.0	T.Walding
2	93/12/05	233.0	30.0	125.0	T.Monang
3	93/12/26	162.0	105.0	78.0	T.Puring
4	94/01/31	139.0	69.4	60.0	

These storm rains were mostly caused by typhoons. The maximum daily rainfalls recorded during the observation period were 233.0 mm on December 5 at Guadalupe, 105.0 mm on December 26 at Mactan and 125.0 mm on December 5 at Talamban.

The daily rainfalls of the three (3) stations were compared to examine the correlation, as shown in Fig. 6.3. The storm rainfall is heavier at the Guadalupe E.S. station with less correlation than those of the two (2) other stations.

The maximum water level during the observation period at the Colon Bridge water level gauging station was recorded on December 5, 1993. This water level was influenced by T.Monang and the runoff peak was supposed to be about 180 m^3/sec.

6.2 Flood Runoff

Due to inadequate observation/recording at the newly installed hydrological stations, particularly, the water level stations in Iloilo and Ormoc, verification of the runoff model and its parameter was carried out only for Guadalupe River in Cebu City.

Rainfall Analysis

Storm rains are mostly caused by typhoons, tropical depressions or tropical storms. Area distribution of daily rainfall was examined by drawing isohyetal maps for the four (4) storm rainfalls, as presented in Fig. 6.4.

The rainfall center is usually located in the northern mountain area, at the Tabunan Station, or the Guadalupe E.S. Station. The rainfall area is small and isolated, although the storm rains were caused by typhoons. Rainfall in the study area is characterized by their spotty and small rainfall area.

The daily rainfall of 233.0 mm at the Guadalupe E.S. Station is evaluated by statistical analysis to be that of a 30-year return period. However, the flood discharge of 175 m^3/s observed at the Colon Bridge on Guadalupe River is estimated to be a discharge of 15-year return period. Therefore, two factors for rainfall analysis, namely conversion of point rainfall and adjustment of rainfall by altitude, were examined using the observation data.

As discussed in Section 4.3, the conversion factor (P/P_0) is estimated at 0.6 so as to adjust the computed peak discharge to that of the observed, while it is estimated at 0.84 by using the formula. Therefore, the conversion factor is further reduced by about 70%.

The adjustment of rainfall by altitude is examined with the observed rainfall at the Guadalupe E.S. Station for the total rainfall from June 1993 to February 1994. The relation between the rainfall amount for 9 months and the elevation of stations is given in Fig. 6.5. The rainfall at Guadalupe E.S. Station is extremely high compared to the other stations. Therefore, the adjustment coefficient for rainfall in altitude is not applied in the following runoff analysis.

Runoff Analysis

The runoff calculation is executed based on data from the new hydrological stations installed in Cebu City, where both rainfall and water level data in the rainy season of 1993 were satisfactorily obtained.

(1) Rating Curve at Water Level Station

Rating curve is established by means of the Manning s formula based on the river survey of Guadalupe River, as presented in Fig. 6.6.

(2) Runoff Calculation by Nakayasu's Unit Hydrograph Method

The runoff calculation is conducted for two observed floods; medium and large scale cases by Nakayasu's Unit Hydrograph Method. The calculation of the mean rainfall of sub-basin area is made using the area conversion factor of 0.6 and the altitude adjustment coefficient of 1.0. The same method used in the Master Plan Study is employed for the effective rainfall calculation.

Flood discharges are estimated for the following two floods. The computation shows almost the same results as the observations, as shown in Figs. 6.7 and 6.8. It is considered that Nakayasu's Unit Hydrograph Method and its parameter are appropriate in the runoff model.

- Case A : December 5, 1993 (Maximum flood during observation period: T. Monang)
- Case B : August 4, 1993 (Medium scale flood during observation period: T. Openg)

7. FLOOD INUNDATION

It is necessary to identify the inundation condition in order to plan and provide an effective control measure and to estimate the benefit which may accrue from the flood control project.

7.1 Flood Inundation Model

Flood Inundation Model

Generally, inundation by floods is classified into two (2) types, the storage type and the flow or diffusion type. Flood inundation analysis is made by either the Two-Dimensional Unsteady Flow Model, the Mushkingum Model, the Simplified Unsteady Model, or some other models.

From the inundation conditions on record, flood discharge beyond the river channel flow capacity widely spread over the low land.

To express the hydraulic condition, the Two-Dimensional Unsteady Flow Model was employed under the following conditions.

(1) The whole flood-prone area is divided into mesh blocks of 250 m by 250 m.

(2) The average ground height of each mesh is obtained using the topographic map with the scale of 1/10,000 prepared in this Study.

(3) Structures such as roads and railways which may hamper the smooth flow of inundation water are taken into consideration assuming them as weirs between the mesh blocks.

(4) Flood discharge overtop at points with low flow capacity and spread over the inundation area.

Basic Equations

The basic equations applied to the model are derived from the following equations:

(1) Euler's Equation of Motion

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=X-\frac{1}{\rho}\frac{\partial P}{\partial X}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=Y-\frac{1}{\rho}\frac{\partial P}{\partial Y}$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=Z-\frac{1}{\rho}\frac{\partial P}{\partial Z}$$

where,

u, v, w	:	velocity of x, y and z directions
X, Y, Z	:	gravity of x, y and z directions
ρ	:	water density (=1.0)
P	:	pressure

(2) Equation of Continuity

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

For actual application to the two-dimensional model, the above expressions are expressed as follows:

(1) Equation of Motion

$$\frac{1}{gA_x}\frac{\partial Q_x}{\partial t}-\frac{Q_x B_x}{gA_x^2}\frac{\partial H}{\partial t}+\frac{\partial H}{\partial x}+\frac{|Q_x|Q_x}{F_x^2}=0$$

$$\frac{1}{gA_y}\frac{\partial Q_y}{\partial t}-\frac{Q_y B_y}{gA_y^2}\frac{\partial H}{\partial t}+\frac{\partial H}{\partial y}+\frac{|Q_y|Q_y}{F_y^2}=0$$

$$F_x=\frac{1}{n}R_x^{2/3}A_x$$

$$F_y=\frac{1}{n}R_y^{2/3}A_y$$

(2) Equation of Continuity

$$\frac{\partial(Bh)}{\partial t}+\frac{\partial Q_x}{\partial x}+\frac{\partial Q_y}{\partial y}=0$$

where,

Q_x, Q_y	:	discharge of x and y directions
A_x, A_y	:	current area of x and y ddirections
B_x, B_y	:	width of x and y directions
R_x, R_y	:	hydraulic depth of x and y directions
g	:	gravity acceleration (9.8 m/s^2)
n	:	Manning s roughness coefficient
H	:	water level
h	:	water depth

The above equations are finally transformed into finite difference for numerical computation, as follows:

(1) Finite Difference Form of Equation of Motion

$$\frac{1}{gA_{I,J}^{n-\frac{1}{2}}}\frac{Q_{I,J}^{n}-Q_{I,J}^{n-1}}{\Delta t}-\frac{\left(\frac{Q_{I,J}^{n}-Q_{I,J}^{n-1}}{2}\right)\cdot\Delta y}{g\cdot\left(A_{I,J}^{n-\frac{1}{2}}\right)^{2}}\frac{H_{I,J}^{n-\frac{1}{2}}-H_{I,J}^{n-\frac{2}{3}}}{\Delta t}+$$

$$\frac{H_{I+\frac{1}{2},J}^{n-\frac{1}{2}}-H_{I-\frac{1}{2},J}^{n-\frac{1}{2}}}{\Delta x}+\frac{\left|Q_{I,J}^{n-1}\right|Q_{I,J}^{n}}{\left\{\frac{1}{n}\cdot\left(\frac{A_{I,J}^{n-\frac{1}{2}}}{\Delta y}\right)\cdot A_{I,J}^{n-\frac{1}{2}}\right\}^{2}}=0$$

(2) Finite Difference Form of Equation of Continuity

$$\frac{(Bh)_{I,J}^{n}-(Bh)_{I,J}^{n-1}}{\Delta t}+\frac{Q_{I+\frac{1}{2},J}^{n-\frac{1}{2}}-Q_{I-\frac{1}{2},J}^{n-\frac{1}{2}}}{\Delta x}+\frac{Q_{I,J+\frac{1}{2}}^{n-\frac{1}{2}}-Q_{I,J-\frac{1}{2}}^{n-\frac{1}{2}}}{\Delta y}=0$$

where,

suffix I, J	:	mesh number of x and y directions
suffix n	:	computative time step number

Initial Condition for Computation

The maximum inundation depth and the inundation area are examined under the probable flood discharge of 2-year, 5-year, 10-year, 20-year, 50-year and 100-year return period. As the initial condition for computation, it is necessary to give the overflow discharge to the inundation area and the overflow section. Under this consideration, the following initial conditions are taken into account:

(1) The overflow sections are selected where the flow capacity is very poor compared with the adjacent stretches.

(2) It is assumed that in the probable flood hydrograph, the surplus discharge over the flow capacity overflows at the overflow section. The overflow discharge at the overflow section is given by the surplus discharge over the flow capacity in the flood hydrograph after subtracting the overflow discharge at the overflow section.

(3) On account of the topography of the Anilao and Malbasag rivers which flow closely in parallel on the mountain slope, flood occurrence on both rivers are considered coincident. Therefore, flood inundation analysis is made presuming that the two rivers overflow at the same time.

Stormwater Inundation

(1) Inundation Model

The stormwater inundation along the primary drainage channel is analyzed by means of non-uniform flow computation for each cross-section of the channel. The inundation area for each channel is delineated by enveloping the inundation width at each cross-section.

Basic Equations are:

$$h_e = \left\{H_2 + \frac{1}{2g}\left(\frac{Q_2}{A_2}\right)^2\right\} - \left\{H_1 + \frac{1}{2g}\left(\frac{Q_1}{A_1}\right)^2\right\}$$

$$Q_1 = A_1 \cdot V_1$$

$$Q_2 = A_2 \cdot V_2$$

where,

h_e	:	difference in hydraulic energy between section 1 and 2
H_1, H_2	:	water level at section 1 and 2
A_1, A_2	:	flow area at section 1 and 2
Q_1, Q_2	:	discharge at section 1 and 2
V_1, V_2	:	flow velocity at section 1 and 2
g	:	gravity acceleration (9.8 m/s_2)

Here, it is assumed that section 1 is the edge of inundation area and section 2 is the channel bank of overflow. The boundary conditions may be defined as follows:

$$A_1 = H_1, A_2 = H_2 \text{ and } V_1, H_1 = 0$$

therefore,

$$h_e = H_2 + \frac{1}{2g}V_2^2 \Rightarrow \frac{1}{2}\left(\frac{n_2^2 \cdot V_2^2}{H_2^{4/3}}\right) \cdot \Delta x = H_2 + \frac{1}{2g}V_2^2$$

$$\Delta x = \frac{3H_2^{4/3}}{gn_2^2}$$

where, Δx is the distance from the channel bank to the inundation edge.

7.2 Inundation Analysis

Verification of Flood Inundation Model

The flood caused in Ormoc City on November 5, 1991 is selected for verification of the flood inundation model. The flood-prone area of Ormoc is divided into mesh blocks of 125 m by 125 m because of its comparatively small size.

(1) Flood Hydrograph

As reported for the November 1991 flood, the flood discharge was dammed up by driftwood and debris stagnating 500 m upstream of the Anilao Bridge, and the temporary dam was breached by flood overflow resulting in the formation of a hydraulic bore. A simple computation of flood run-off shows that the peak flood discharges of Anilao and Malbasag rivers were 600-800 m^3/s and 250-350 m^3/s, respectively. Hence, the flood hydrograph of the objective flood for Anilao River is estimated by the dam breach equation below.

$$Q_0 = B \cdot \sqrt{\frac{8}{27} g H_0^3}$$

$$Q(t) = Q_0 \cdot \left(1 - \frac{t}{T}\right)^3$$

$$T = 3 \cdot \frac{BL}{b} \sqrt{\frac{3}{(2gH_0)}}$$

where,

H_0	:	maximum water depth (5.0 m)
g	:	gravity acceleration (9.8 m/s^2)
T	:	reservoir emptying time (s)
B	:	reservoir width (100 m)
L	:	reservoir length (550 m)
b	:	dam breach width (40 m)

Fig. 7.1 shows the estimated flood hydrograph for Anilao River with a peak discharge of 762 m3/s. The probable flood hydrograph of a 50-year return period is adapted for Malbasag River

(2) Computation Results

The adequacy of this model is justified from the fact that the flood water depth and the flood area are similar compared with the simulation results of the flood interview survey by, as shown in Fig. 7.2.

Results of Inundation Analysis

The maximum inundation areas and depths of a 50-year return period flood in each river expressed both in patterns and figures are shown in Fig.7.3 to 7.5.

ANNEX

ANNEX: FLOOD IN ILOILO ON JULY 29, 1994

A.1 Flood Runoff

Iloilo City had sufferred from widespread flooding on July 29 to August 1, 1994, caused by unusual heavy monsoon rains. A big amount of rainfall (319.5 mm/day) was recorded at the PAGASA Station near the Iloilo Airport on July 29 (9:00 a.m. of July 29 to 8:00 a.m. of July 30, 1994). The heavy rain lasted for three days from July 26 with a 3-day total rainfall of 715.2 mm, as shown in Fig. A.1. Other than the Iloilo Airport Station, two (2) other rainfall stations in the Jaro river basin, namely ARIS (Aganan River Irrigation System) Damsite and Cabatuan, had recorded daily rainfall during the flood as summarized below:

(Unit: mm/day)

Station	July 26	July 27	July 28	July 29	July 30	Total
Iloilo	36.5	50.4	118.3	319.5	190.6	715.2
ARIS	34.1	18.2	25.5	308.1	259.0	644.9
Cabatuan	14.8	9.5	11.5	90.2	61.7	187.7

Heavy rains concentrated in the downstream area of Aganan River and Iloilo City. The hourly distribution was recorded at only the Iloilo Station, therefore, the runoff simulation is carried out assuming the same houry distribution of rain for both ARIS and Cabatuan as shown in Table A.1.

The flood runoff computation for 11:00 p.m. of July 29 to 9:00 a.m. of July 31 is made with the same model and parameters as discussed in Section 5: FLOOD RUNOFF ANALYSIS, while the saturation rainfall is given 0 mm due to the antecedent rainfall from July 26.

The peak flood discharge is computed to be 1,470 m^3/s at the downstream of Jaro River, 980 m^3/s for Aganan River and 480 m^3/s for Tigum River, and their flood hydrographs are shown in Fig. A.2. The estimated flood discharge is evaluated to correspond to that of a 50-year return period.

A.2 Flood Condition

Flood Inundation

Due to the big discharge, the flood overflowed Aganan River and Tigum River. The overflow point was at the right bank of Aganan River in Barangay Amparo and Pavia. Firstly, the floodwater came from the lower stream of Aganan River. The floodwater cascaded down the south resulting in the backwater effect at the left bank of Tigum River located 750 m north from the confluence point with Aganan River.

This massive stream of floodwatesr brought flooding to Mandurriao, the southwest area of Jaro and the city proper of Iloilo. Under this unpredictable circumstance, 80% of Iloilo City area had been submerged with the destruction of infrastructures and human activities for two days/nights, especially in low-lying areas.

The height of the floodwater recorded in Iloilo Province was about 0.5 m on average while 2.0 m was recorded at some observation points.

Many of the affected families are from Jaro District in Iloilo City and Oton in Iloilo Province. The number of affected families were 4,873 and 5,648, respectively. Consequently, more than two-thirds of the casualties and houses destroyed were reported to have occurred in those places.

Flood Damage

Damage to agricultural products, palay (including stocks) occupy more than 72% of the total damage in both Iloilo City and Iloilo Province. Remarkably, 97% of all palay damage were in Iloilo Province. On the other hand, 72% of all fishpond damages were in Iloilo City.

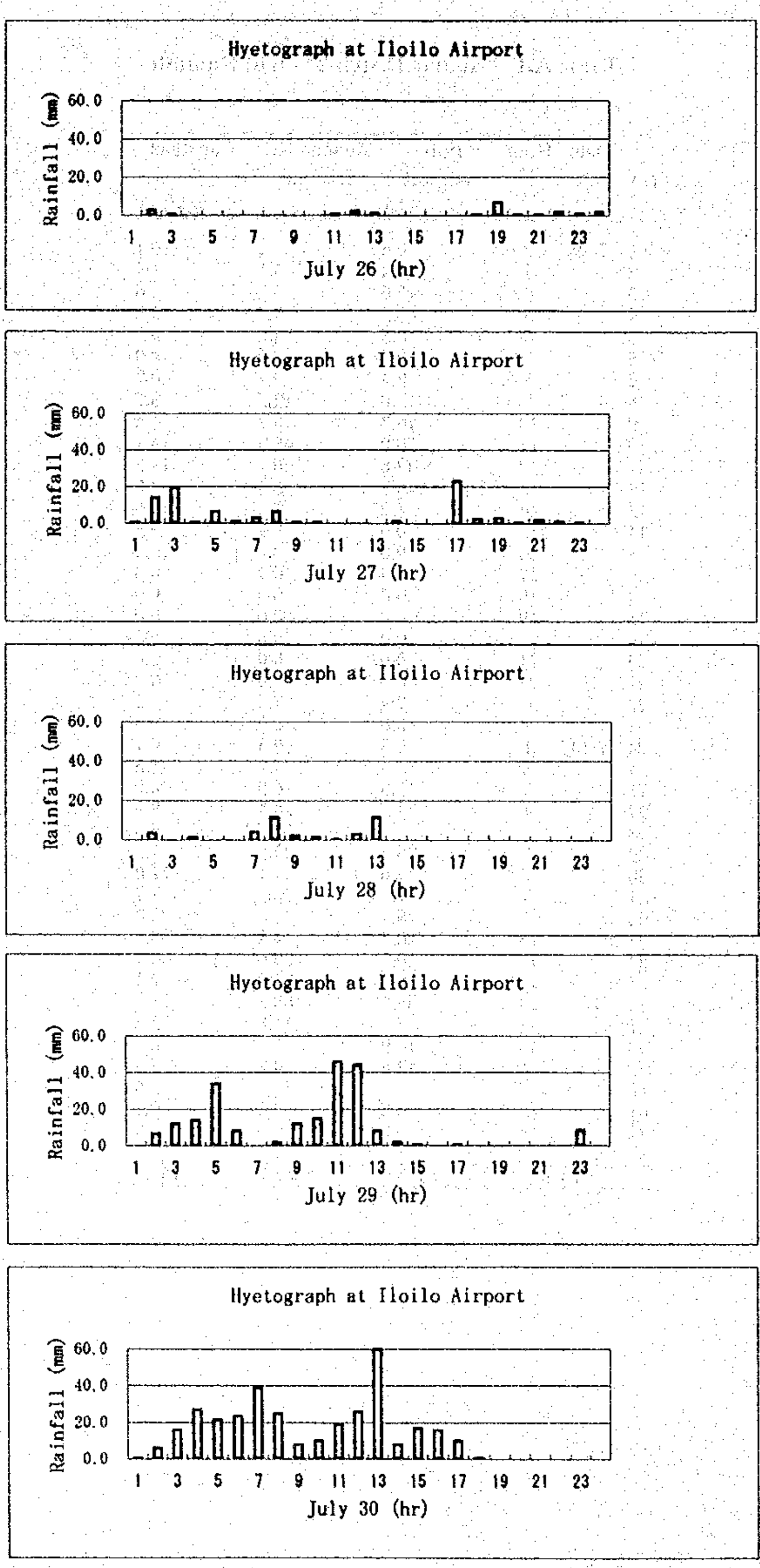
Finally, although there are some missing data, 77% of all national road damages were in the Iloilo Province while damage to flood control and drainage facilities were reported to be only in Iloilo City.

As of August 3, the damage reported during the flooding are as follows:

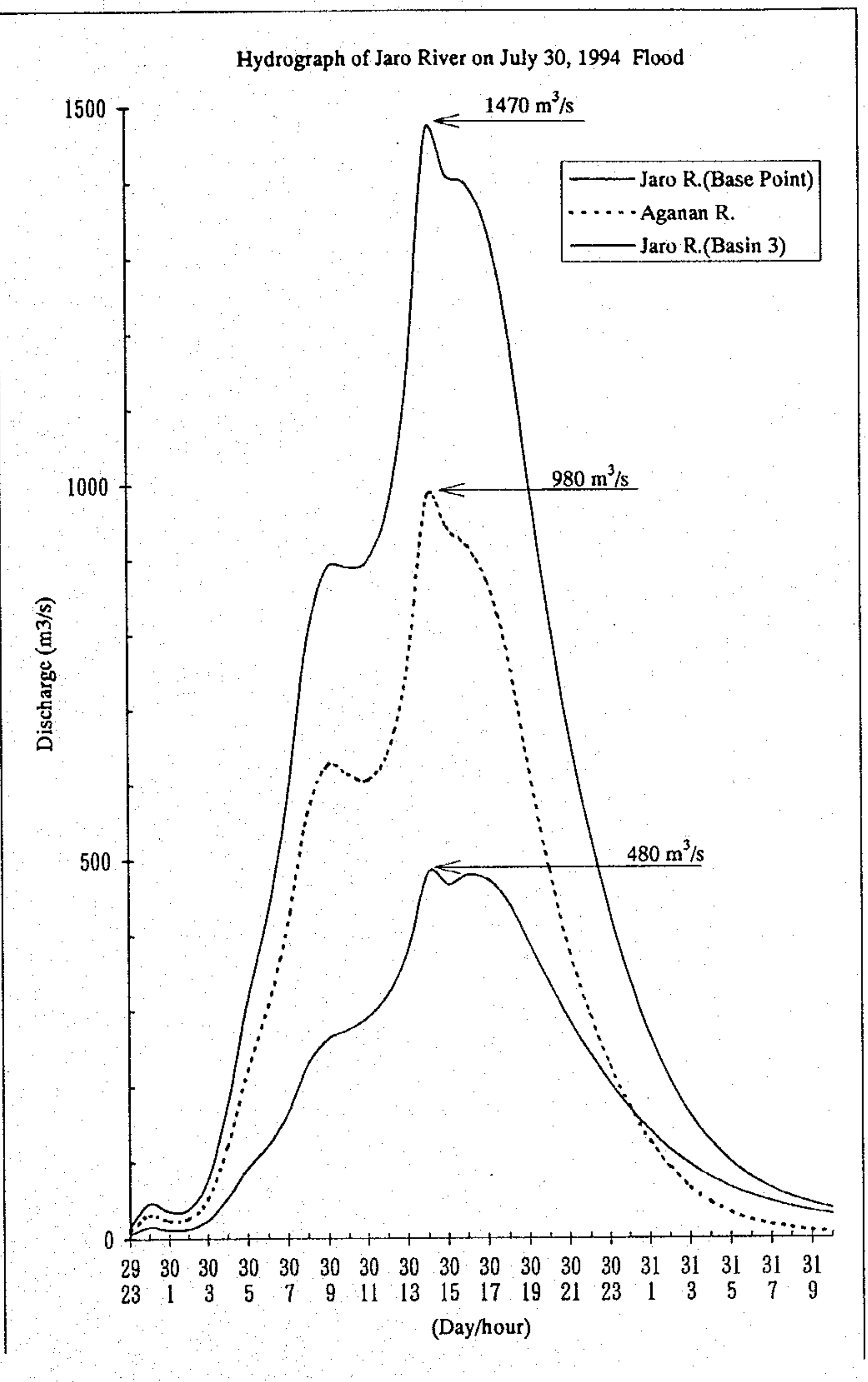
(1)	Affected Families		:	24,937
	(a)	Total/partial destruction of houses	:	2,299
	(b)	Casualties;		
		- Dead	:	9
		- Injured	:	10
(2)	Agricultural Products (in pesos)			
	(a)	Palay	:	39,067,968
	(b)	Livestock	:	6,133,220
	(c)	Fishponds	:	6,983,905
	(d)	Vegetables	:	2,586,680
	(c)	Corn	:	1,241,004
	(d)	Fruit Trees	:	61,000
	(e)	Palay (Stock)	:	5,250,000
(3)	Infrastructures (in pesos)			
	(a)	National Roads	:	6,140,000
	(b)	Bridges	:	2,050,000
	(c)	Flood Control	:	5,000,000
	(d)	Drainage lines	:	600,000
	Total Damage (in pesos)		:	75,113,777

Table A.1 Hourly Distribution of Rainfall

No	Date	Hour	Iloilo Airport (PAGASA)	Aganan RIS Damsite	Cabatuan (PAGASA)
1	7/29	2	0.6	0.1	0.1
2		3	14.2	3.1	1.4
3		4	16.6	3.6	1.6
4		5	40.3	8.7	3.9
5		6	9.5	2.0	0.9
6		7	0.0	0.0	0.0
7		8	2.4	0.5	0.2
8		9	13.0	12.5	3.7
9		10	16.3	15.7	4.6
10		11	50.0	48.2	14.1
11		12	47.8	46.1	13.5
12		13	8.7	8.4	2.5
13		14	2.2	2.1	0.6
14		15	0.9	0.9	0.3
15		16	0.0	0.0	0.0
16		17	0.9	0.9	0.3
17		18	0.0	0.0	0.0
18		19	0.0	0.0	0.0
19		20	0.0	0.0	0.0
20		21	0.0	0.0	0.0
21		22	0.0	0.0	0.0
22		23	7.7	7.4	2.2
23		24	0.0	0.0	0.0
24	7/30	1	0.5	0.5	0.1
25		2	5.4	5.2	1.5
26		3	17.5	16.9	4.9
27		4	29.5	28.4	8.3
28		5	23.5	22.7	6.6
29		6	25.7	24.8	7.3
30		7	42.6	41.1	12.0
31		8	27.3	26.3	7.7
32		9	8.7	11.8	2.8
33		10	10.9	14.8	3.5
34		11	20.6	28.0	6.7
35		12	28.2	38.3	9.1
36		13	65.1	88.5	21.1
37		14	8.7	11.8	2.8
38		15	18.9	25.7	6.1
39		16	17.8	24.2	5.8
40		17	11.1	15.1	3.6
41		18	0.6	0.8	0.2
42		19	0.0	0.0	0.0
	Total		593.7	585.1	160.0



THE STUDY ON THE FLOOD CONTROL FOR RIVERS IN THE SELECTED URBAN CENTERS	Fig. A.1 Hourly Rainfall at Iloilo Station in July 1994
JAPAN INTERNATIONAL COOPERATION AGENCY	



THE STUDY ON THE FLOOD CONTROL FOR RIVERS IN THE SELECTED URBAN CENTERS	Fig. A.2 Computed Flood Hydrograph of Jaro River in July 1994
JAPAN INTERNATIONAL COOPERATION AGENCY	