2.3 Runoff Ratio and Actual Evapotranspiration

2.3.1 Water Balance Method

(1) Equation Approach

Based on the monthly mean rainfall, evapotranspiration and discharge at each discharge reference point, water balance study was carried out by using the following equation;

$$P = (Q2-Q1) + Evta + (G2-G1) \pm dS \quad \text{(Equation 2.19)}$$

where P : rainfall depth (mm),
Evta : actual evapotranspiration depth (mm)
dS : intermediate storage change depth (mm)
Q1 : surface inflow depth (mm),
Q2 : surface outflow depth (mm)
G1 : groundwater inflow depth (mm)
G2 : groundwater outflow depth (mm)

By applying the long term simulation period into the above water balance equation, the following conditions are considered;

a) Surface Inflow (: Q1)

In this Study, surface inflow (: Q1) is neglected to be zero, because the selected discharge reference points are located at end of each catchment area.

b) Groundwater (: G1, G2)

During a certain period, runoff volume is derived primarily from surface outflow, whereas during dry periods all runoff may be contributed by groundwater outflow/ or base flow (G2). In general, G2 is not subject to wide fluctuations and is indicative of aquifer characteristics within a basin. In order to estimate the actual evapotranspiration by using [Equation 2.19], ignoring groundwater inflow (: G1) from other basins, and the volume of G2 contributes in the volume of the surface outflow (Q2).

c) Intermediate Storage Change (: dS)

The significance of dS is a intermediate storage change under the ground surface at a certain period, and "+" (plus) indicates a increase of the storage volume, "-" (minus) indicates a decrease of the storage volume. It consists of the following three factors;

- an increase of the surface storage volume in the lake, pond, swamp, river and other storage reservoirs
- an change of the groundwater storage under the groundwater surface
- an change of saturate soil volume above the groundwater surface

Assuming that rainfall and groundwater at a same basin are circulating through long period, the volume of dS is not cumulative and can be ignored if the starting and finishing points of the study are chosen to coincide with the same period. Therefore, the volume of dS in this Study was neglected.

(2) Mean Depth over An Area

Using the obtained data in the pervious chapter, water balance study was carried out as the following steps;

a) Thissen's Method

In this study, Thiessen's method was used to obtain rainfall, runoff and evapotranspiration depths over area. The applied stations are same as the selected 33 meteorological stations (Refer to Section 1.1) and Figure-2.8 shows Thiessen's Polygon. The polygons were formed by the perpendicular bisectors of the lines joining nearby stations and established area of each polygon is determined and is used to weight of the amounts of the station in the center of polygon.

b) Mean Rainfall Depth

The missing data were determined by correlation analysis among the stations, and the computed mean rainfall depth at the selected 31 discharge reference points were shown in Table-2.7.

Especially, number of the selected rainfall stations for Litoranea area were not enough to apply the water balance method to analyze all basins in Litoranea area, therefore an existing Iso-hyetal map obtained by COPEL was used to determine mean rainfall depth for two stations in Litoranea area.

c) Mean Runoff Depth

The annual surface runoff depth over the same area was computed by Thiessen's method at the selected 31 discharge reference points. The results of computed mean runoff depth were shown in Table-2.8.

d) Mean Actual Evapotranspiration Depth

The annual actual evapotranspiration depth over the same area was computed by applying a modified equation of (Equation 2.19) as follows;

$$Evta = P - Q2$$

where, Evta : annual actual evapotranspiration (mm)
P : annual rainfall (mm)
Q2 : annual surface outflow (mm)

The results of computed mean actual evapotranspiration depth were shown in Table-2.9.

e) Mean Potential Evapotranspiration Depth

The annual mean potential evapotranspiration depth were computed over the same area to determine the relation between actual evapotranspiration and potential evapotranspiration. The results of computed mean actual evapotranspiration depth were shown in Table-2.10.

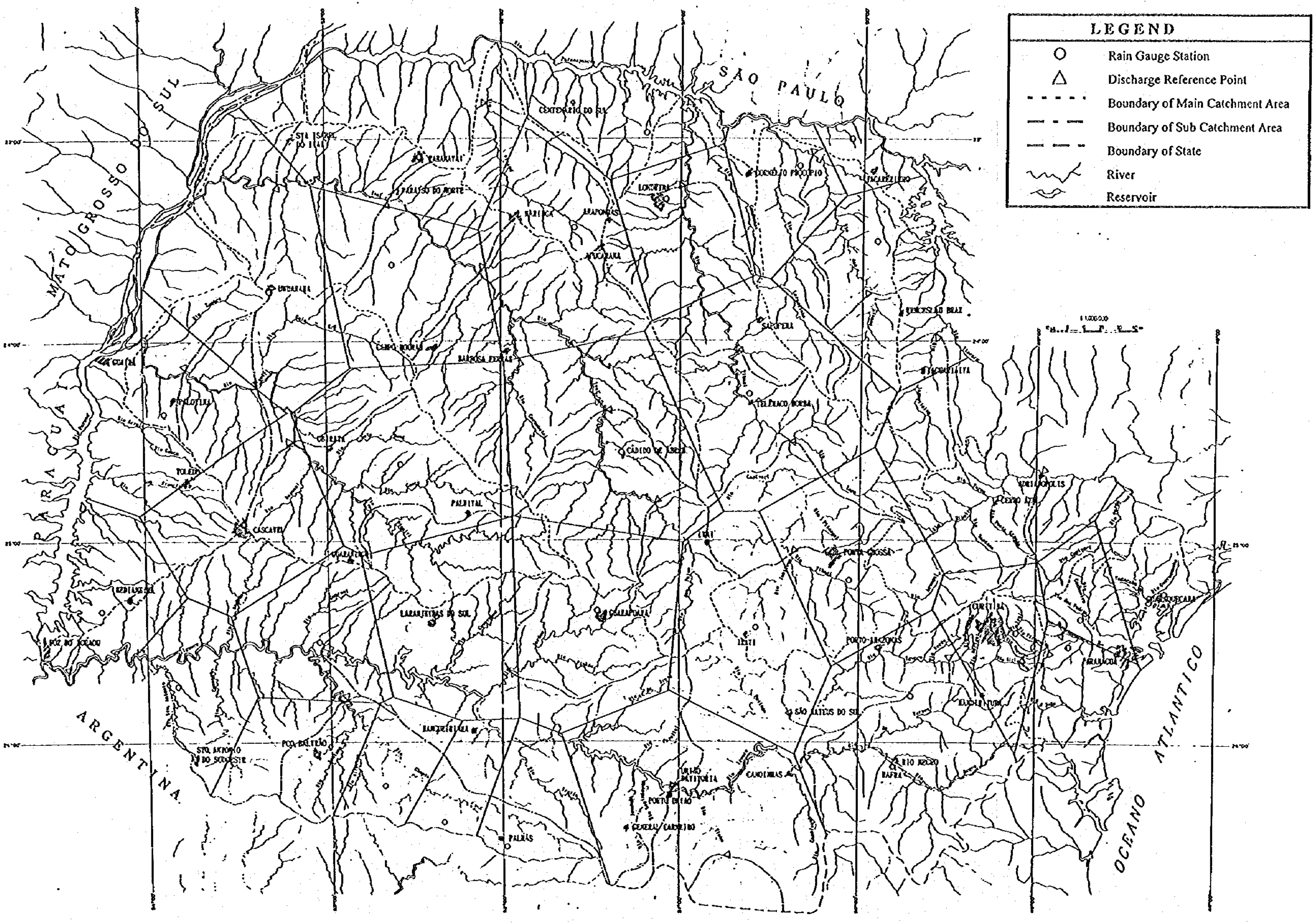

Figure-2.8 Thiessen's Polygon Diagram

Table-2.7 Results of Computed Annual Mean Rainfall Depth

Mean Rainfall Depth by Stations

Unit : (mm/year)

	Itarare	Cinzas		Tibagi				Pirapo	Ivai					Piquiri			
Year	64-242-000	64-360-000	64-370-000	64-444-000	64-465-000	64-491-000	64-507-011	64-550-000	64-625-000	64-645-000	64-675-002	64-685-000	64-693-000	64-771-500	64-795-000	64-820-000	64-830-000
1974	1147.3	1669.7	1549.3	1275.1	1375.3	1536.3	1645.7	1829.6	1357.3	1558.9	1723.3	1744.7	1742.1	1354.0	1467.7	1522.7	1529.2
1975	1302.3	1427.5	1324.2	1422.9	1456.5	1506.4	1546.1	1672.2	1443.2	1415.4	1516.6	1552.7	1581.4	1778.6	1860.7	1797.1	1769.4
1976	1551.7	1606.1	1639.7	1720.6	1703.1	1686.6	1722.3	1971.4	1896.8	1898.1	1919.9	1907.7	1887.4	1756.8	1862.9	1824.0	1786.8
1977	1017.7	1250.8	1150.0	1375.6	1397.7	1425.4	1479.2	1717.8	1464.4	1486.9	1533.1	1518.0	1523.7	1511.4	1485.0	1489.8	1478.6
1978	1067.4	1143.4	1142.6	1274.7	1256.1	1226.2	1246.4	1104.7	1357.8	1363.2	1318.3	1294.1	1272.7	1452.5	1396.8	1374.8	1341.9
1979	1250.7	1314.3	1203.6	1566.7	1568.1	1570.8	1527.1	1501.6	1727.6	1670.8	1630.6	1616.5	1616.2	1979.4	2013.6	1964.9	1998.8
1980	1416.3	1695.4	1639.2	1683.2	1687.0	1698.8	1787.5	1944.4	1864.2	1823.6	1876.0	1865.0	1825.8	2138.1	2118.4	2005.4	1945.5
1981	1211.0	1326.3	1314.5	1164.2	1182.6	1224.1	1292.1	1561.6	1471.5	1459.4	1531.6	1547.8	1553.9	1866.1	1904.8	1869.3	1845.5
1982	1717.5	1911.1	1856.7	1798.2	1838.5	1907.5	1911.0	1740.3	1945.1	1924.1	1876.6	1847.3	1813.9	2381.0	2273.1	2133.0	2098.3
1983	1876.1	1872.2	1765.5	2324.8	2275.4	2184.9	2162.5	2136.3	2645.9	2503.6	2360.9	2347.0	2314.3	2940.5	2828.7	2696.8	2716.4
1984	1229.3	1335.2	1214.6	1619.9	1599.5	1560.9	1508.5	1457.5	1818.8	1673.9	1572.1	1580.2	1556.0	2083.6	1882.8	1783.3	1744.1
1985	917.3	1212.1	1180.4	957.4	988.0	1046.4	1086.3	1128.7	1037.4	933.0	1007.6	1019.4	1040.8	1466.9	1419.5	1391.3	1347.4
1986	1480.4	1763.8	1693.9	1586.9	1621.9	1671.8	1637.8	1428.3	1634.0	1568.4	1533.0	1527.3	1514.5	1889.4	1925.4	1829.5	1843.7
1987	1205.6	1358.0	1332.1	1496.8	1492.1	1478.3	1545.2	1802.9	1661.0	1635.3	1735.2	1730.8	1721.2	2067.8	2181.0	2059.7	2020.8
1988	1346.3	1244.9	1231.0	1234.8	1241.1	1249.5	1267.6	1235.6	1139.9	1061.4	1161.2	1163.1	1168.9	1546.2	1557.8	1505.2	1460.5
1989	1465.7	1740.3	1675.2	1587.1	1624.9	1688.6	1728.5	1742.3	1848.3	1821.1	1822.1	1791.7	1758.9	2130.7	2168.8	2065.8	2027.3
1990	1465.1	1515.3	1471.5	2100.2	2034.7	1896.3	1803.5	1680.8	2033.6	1905.8	1838.8	1848.6	1826.5	2079.1	2130.0	2038.9	2064.5
1991	1200.7	1360.0	1415.3	1350.5	1348.1	1336.1	1352.8	1269.6	1604.3	1600.6	1545.3	1536.0	1492.1	1719.5	1883.2	1764.3	1744.3
1992	1311.3	1531.6	1475.1	1698.6	1703.5	1696.3	1732.9	1777.4	1955.0	1963.3	1937.6	1926.3	1909.5	2257.2	2208.5	2151.8	2140.5
1993	1529.2	1547.2	1532.5	1965.1	1920.4	1802.8	1768.2	1600.3	1963.4	1932.0	1861.8	1787.0	1724.4	2178.6	2170.1	2035.3	1956.7
Mean	1335.4	1491.3	1440.3	1560.2	1565.7	1569.7	1587.6	1615.2	1694.5	1659.9	1665.1	1657.6	1642.2	1928.9	1936.9	1865.1	1843.0

	Iguacu											Rebeira	Litoranea	
Year	65-010-000	65-025-000	65-035-000	65-060-000	65-310-000	65-895-002	65-993-000	65-175-000	65-260-000	65-825-000	65-960-000	81-200-000	82-170-000	82-195-000
1974	1526.2	1348.1	1299.8	1262.5	1265.0	1312.4	1429.7	1211.8	1346.1	1193.5	1567.5	1132.8		
1975	1532.1	1342.8	1384.9	1408.1	1576.6	1701.2	1813.1	1485.2	1887.4	1607.4	2192.6	1355.1		
1976	1656.4	1553.6	1615.5	1686.3	1706.3	1728.0	1723.1	1754.1	1604.0	1882.4	1730.3	1558.0		
1977	1483.4	1305.6	1420.5	1482.0	1587.0	1592.3	1647.6	1676.1	1635.2	1506.2	1740.1	1138.6		
1978	1172.3	1097.1	1135.6	1190.5	1204.6	1291.0	1267.3	1220.9	1137.1	1314.1	1331.9	1090.3		
1979	1425.1	1286.4	1340.4	1413.6	1610.6	1809.2	1957.9	1460.0	1925.3	1940.4	2325.4	1356.8		
1980	1760.2	1591.9	1683.9	1753.1	1830.0	1900.3	1852.9	1892.6	1821.5	2065.4	1827.6	1425.2		
1981	1316.3	1079.5	1105.3	1136.6	1216.8	1442.1	1562.1	1177.3	1322.8	1824.6	1791.6	1134.8		
1982	1673.1	1577.7	1650.8	1713.3	1806.5	2007.0	2144.1	1807.3	1885.8	2196.7	2377.7	1700.7		
1983	2135.9	2036.9	2078.8	2153.1	2468.2	2764.3	2860.6	2170.4	3060.4	3164.2	3382.5	2016.9		
1984	1583.6	1476.0	1486.5	1524.2	1596.1	1797.0	1860.3	1515.7	1701.2	2213.2	2027.2	1350.6		
1985	1071.6	955.0	966.5	978.4	1003.8	1137.0	1190.3	1001.0	1024.6	1268.5	1334.2	846.9		
1986	1661.2	1528.8	1489.7	1477.2	1461.9	1615.3	1739.1	1414.5	1477.1	1885.1	1949.8	1458.3		
1987	1379.9	1296.2	1325.6	1375.0	1460.3	1641.6	1777.0	1390.6	1572.6	1845.1	2007.8	1263.0		
1988	1462.5	1293.3	1198.7	1142.1	1178.4	1298.8	1345.6	1011.3	1404.9	1282.3	1461.9	1349.5		
1989	1689.7	1464.0	1456.5	1474.9	1593.7	1813.0	1905.2	1455.3	1839.7	2218.7	2162.3	1440.6		
1990	1943.3	1799.8	1833.9	1898.8	2021.6	2126.2	2330.5	1910.6	2200.6	2105.8	2877.4	1674.6		
1991	1297.2	1168.5	1215.7	1265.3	1280.0	1456.2	1512.3	1321.5	1214.3	1913.8	1646.4	1182.5		
1992	1581.2	1459.8	1527.3	1593.3	1726.3	1945.1	2049.0	1673.8	1894.3	2255.4	2296.4	1405.3		
1993	1794.1	1669.8	1701.2	1744.0	2091.4	2173.2	2109.4	1767.0	2818.4	2185.1	2033.3	1681.6		
Mean	1557.3	1416.5	1445.9	1483.6	1584.2	1725.6	1802.9	1515.9	1738.7	1893.4	2003.2	1378.1	*) 2537.7	*) 3300.0

Note; *) It was determined by using an existing iso-hyetal map (COPEL)

Table-2.8 Results of Computed Annual Mean Runoff Depth

Mean Runoff Depth by Stations

Unit : (mm/year)

	Itarare	Cinzas		Tibagi				Pirapo	Ivai					Piquiri			
Year	64-242-000	64-360-000	64-370-000	64-444-000	64-465-000	64-491-000	64-507-011	64-550-000	64-625-000	64-645-000	64-675-002	64-685-000	64-693-000	64-771-500	64-795-000	64-820-000	64-830-000
1974	595.8	533.7	537.9	477.5	539.6	558.1	570.1	644.1	426.8	470.5	553.6	590.4	580.4	463.5	518.3	602.1	581.8
1975	667.0	596.1	466.1	603.9	586.5	561.7	588.7	506.1	630.1	662.6	602.2	628.7	586.9	692.3	756.2	726.6	705.0
1976	899.3	830.5	752.5	807.2	827.3	808.6	784.0	724.9	773.5	815.2	719.4	751.2	710.2	892.9	885.0	804.8	724.3
1977	486.7	446.6	314.4	486.1	510.9	495.5	512.3	567.4	405.6	453.2	463.6	511.8	520.7	463.8	543.0	585.7	527.0
1978	396.0	350.4	216.4	352.2	373.5	366.2	334.5	347.2	397.4	390.7	316.6	330.6	329.2	361.3	362.0	393.6	334.1
1979	491.4	457.0	274.9	583.2	524.3	502.9	455.7	340.2	673.2	652.8	594.5	573.2	540.9	882.5	984.1	798.0	778.2
1980	643.6	697.4	515.6	652.0	630.9	619.3	649.7	652.4	714.0	745.7	675.3	682.2	635.7	901.7	886.5	844.2	762.9
1981	440.0	449.2	379.0	326.5	346.4	381.1	407.4	533.9	388.5	484.7	494.2	515.2	501.1	854.8	941.4	792.1	715.9
1982	726.5	826.4	699.3	810.1	855.5	853.8	816.9	646.6	988.9	986.2	833.5	824.7	827.1	1214.0	1418.2	1100.1	1048.1
1983	1347.4	1072.8	952.6	1420.8	1438.1	1413.5	1356.4	940.5	1719.2	1664.6	1357.2	1398.8	1489.9	1797.0	1949.2	1663.8	1640.6
1984	415.0	321.5	208.9	648.6	626.3	579.1	488.6	390.2	704.5	681.1	541.0	541.6	578.1	848.3	775.6	673.7	618.9
1985	307.4	249.6	246.8	283.1	284.0	295.9	295.4	342.6	313.2	382.3	403.2	401.6	442.5	479.3	545.9	565.0	512.6
1986	443.9	431.7	360.2	406.3	418.0	460.1	435.9	273.3	453.9	472.0	520.0	488.9	484.2	689.9	765.1	643.8	611.1
1987	715.3	600.9	478.6	715.6	686.3	670.0	662.1	463.6	761.4	799.4	681.6	674.1	701.2	1018.6	1099.2	937.1	787.0
1988	453.1	401.5	288.4	372.8	372.9	376.3	370.8	299.8	416.9	449.3	437.3	418.7	432.5	558.6	603.6	546.6	499.2
1989	723.5	704.6	603.5	645.5	637.8	627.4	636.4	386.0	872.6	938.0	757.3	717.8	729.8	1024.6	1077.7	934.3	870.9
1990	954.4	750.9	710.8	1150.5	1094.4	997.8	937.4	542.5	1317.8	1227.6	994.9	984.8	940.7	1374.9	1431.3	1243.1	1127.5
1991	566.8	413.4	424.3	369.2	369.5	374.6	340.9	309.3	344.8	351.7	357.1	344.7	369.3	496.6	544.6	511.0	481.6
1992	654.0	597.5	616.4	800.6	794.6	747.1	728.5	497.7	1045.1	1015.4	902.1	848.2	811.1	1148.3	1364.4	1197.6	1103.7
1993	721.4	584.9	563.5	903.1	879.9	756.0	727.6	446.1	969.1	950.0	772.8	710.4	689.9	949.7	1072.2	911.2	842.1
Mean	632.4	565.8	480.5	640.7	639.8	622.3	604.9	492.7	715.8	729.7	648.9	646.9	645.1	855.6	926.2	823.7	763.6

	Iguacu											Rebeira	Litoranea	
Year	65-010-000	65-025-000	65-035-000	65-060-000	65-310-000	65-895-002	65-993-000	65-175-000	65-260-000	65-825-000	65-960-000	81-200-000	82-170-000	82-195-000
1974	695.7	464.7	432.3	387.1	489.2	544.8	641.5	518.2	611.8	603.9	671.1	572.9	1744.4	2641.9
1975	961.8	749.7	699.6	644.9	627.7	771.3	738.3	519.4	837.7	843.8	937.8	560.1	2117.4	3287.5
1976	1049.8	820.1	799.7	790.0	807.9	793.3	748.5	756.6	1131.5	915.9	730.7	676.1	2090.3	2837.2
1977	736.5	594.1	523.8	498.3	566.8	554.0	556.9	591.5	738.4	557.2	528.8	447.7	2012.1	3467.0
1978	484.4	332.8	260.8	277.0	329.6	293.9	325.6	350.4	351.6	388.6	397.4	373.8	1256.1	1802.4
1979	618.8	519.9	447.2	494.4	644.0	777.2	735.6	550.5	864.3	880.7	1228.6	404.0	1891.4	2687.0
1980	851.7	746.7	674.9	661.1	740.2	672.5	651.8	765.6	1021.1	940.1	792.7	515.6	1922.3	2823.4
1981	663.7	437.5	368.9	379.1	451.9	541.7	547.0	437.1	561.0	740.6	736.2	422.2	2184.1	3035.6
1982	778.3	706.5	660.1	754.3	818.6	1119.0	1009.3	703.3	1149.0	1291.9	1277.3	548.2	1936.2	3016.2
1983	1215.1	1057.2	1243.0	1092.8	1460.8	2000.7	1715.2	1185.9	2196.3	2220.9	2528.4	1144.8	2746.2	4429.9
1984	723.4	718.0	711.8	587.2	685.8	745.8	710.5	651.6	932.5	961.9	896.0	570.7	1511.8	1343.8
1985	400.4	316.9	276.9	254.6	274.4	379.6	395.1	252.3	345.8	448.3	402.2	377.3	1202.7	1270.9
1986	527.1	409.8	367.6	345.0	389.9	468.0	495.4	356.8	568.8	593.0	819.1	385.8	1308.1	1725.4
1987	724.9	614.2	613.6	646.3	648.2	721.1	707.8	588.5	814.9	941.1	959.2	520.0	1348.4	2027.5
1988	563.1	478.5	445.5	407.4	477.3	509.8	472.0	468.4	787.3	553.5	576.0	460.1	1683.4	2619.4
1989	757.1	600.2	594.5	586.9	722.1	780.3	753.5	738.2	924.9	995.2	1086.8	519.1	1728.9	3840.8
1990	978.1	1315.9	991.3	1006.8	1112.8	1188.6	1121.8	1070.1	1334.9	1231.1	1669.5	749.4	2007.9	2882.9
1991	471.8	457.2	343.6	330.9	402.6	431.6	416.5	430.5	536.6	519.4	596.0	482.4	1278.6	2080.1
1992	791.3	611.9	640.3	641.8	862.5	1144.1	952.4	721.8	1058.8	1212.0	1326.1	515.3	1558.5	2651.3
1993	831.6	743.4	741.2	709.7	764.0	869.3	798.9	681.2	941.3	1075.8	1016.3	669.8	1381.0	2468.8
Mean	741.2	634.8	591.8	574.6	663.8	765.3	724.7	616.9	884.9	895.8	958.8	545.8	1745.5	2646.9

Table-2.9 Results of Computed Annual Mean Actual Evapotranspiration Depth

Actual Evapotranspiration ("Mean Rainfall Depth" - "Mean Runoff Depth")

Unit : (mm/year)

	Itarare	Cinzas		Tibagi				Pirapo	Ivai					Piquiri			
Year	64-242-000	64-360-000	64-370-000	64-444-000	64-465-000	64-491-000	64-507-011	64-550-000	64-625-000	64-645-000	64-675-002	64-685-000	64-693-000	64-771-500	64-795-000	64-820-000	64-830-000
1974	551.4	1135.9	1011.5	797.6	835.6	978.2	1075.6	1185.5	930.5	1088.4	1169.6	1154.3	1161.7	890.5	949.4	920.5	947.4
1975	635.2	831.4	858.1	819.0	870.0	944.7	957.4	1166.1	813.1	752.8	914.4	924.0	994.5	1086.3	1104.5	1070.5	1064.4
1976	652.4	775.5	887.1	913.4	875.8	878.1	938.3	1246.5	1123.3	1082.9	1200.5	1156.5	1177.2	863.9	977.8	1019.2	1062.6
1977	531.0	804.2	835.6	889.5	886.8	929.9	967.0	1150.4	1058.8	1033.7	1069.6	1006.2	1003.0	1047.6	942.0	904.1	951.6
1978	671.4	793.0	926.2	922.5	882.6	860.0	912.0	757.5	960.4	972.5	1001.6	963.5	943.5	1091.2	1034.9	981.2	1007.8
1979	759.3	857.3	928.7	983.5	1043.7	1067.9	1071.4	1161.4	1054.4	1018.0	1036.1	1043.3	1075.3	1096.9	1029.5	1166.9	1220.6
1980	772.6	998.1	1123.5	1031.2	1056.0	1079.5	1137.8	1292.0	1170.2	1077.9	1200.7	1182.8	1190.1	1236.4	1231.8	1161.2	1182.6
1981	771.0	877.1	935.5	837.7	836.2	843.0	884.7	1027.7	1083.0	974.7	1037.4	1032.6	1052.8	1011.3	963.4	1077.1	1129.6
1982	991.0	1084.6	1157.3	988.1	982.9	1053.7	1094.1	1093.7	956.2	938.0	1043.1	1022.7	986.8	1167.0	854.9	1033.0	1050.2
1983	528.7	799.4	812.9	904.0	837.3	771.4	806.1	1195.8	926.6	839.0	1003.7	948.2	824.4	1143.6	879.5	1033.0	1075.8
1984	814.2	1013.7	1005.8	971.3	973.2	981.8	1020.0	1067.2	1114.3	992.8	1031.1	1038.6	977.9	1235.3	1107.2	1109.6	1125.2
1985	609.8	962.5	933.6	674.3	703.9	750.5	790.9	786.1	724.2	550.7	604.4	617.8	598.4	987.6	873.6	826.3	834.8
1986	1036.4	1332.2	1333.7	1180.7	1203.9	1211.7	1201.9	1154.9	1180.1	1096.3	1013.0	1038.4	1030.3	1199.4	1160.3	1185.7	1232.6
1987	490.3	757.2	853.5	781.2	805.7	808.2	883.2	1339.3	899.6	835.9	1053.6	1056.7	1020.0	1049.2	1081.8	1122.7	1233.8
1988	893.1	843.4	942.6	862.0	868.2	873.2	896.8	935.8	723.0	612.1	723.9	744.4	736.4	987.5	954.2	958.5	961.3
1989	742.3	1035.8	1071.7	941.6	987.1	1061.2	1092.1	1356.3	975.7	883.0	1064.8	1074.0	1029.2	1106.1	1091.0	1131.5	1156.4
1990	510.7	764.4	760.7	949.7	940.3	898.5	866.1	1138.3	715.8	678.2	843.9	863.8	885.9	704.1	698.7	795.7	936.9
1991	633.9	946.7	991.0	981.4	978.5	961.5	1011.9	960.2	1259.5	1248.9	1188.2	1191.4	1122.8	1223.0	1338.6	1253.2	1262.8
1992	657.3	934.1	858.7	898.0	908.9	949.1	1004.4	1279.7	909.9	947.8	1035.5	1078.1	1098.4	1108.8	844.1	954.2	1036.8
1993	807.7	962.2	969.1	1062.0	1040.5	1046.7	1040.6	1154.2	994.3	981.9	1089.0	1076.6	1034.5	1228.9	1097.9	1124.1	1114.5
Mean	703.0	925.4	959.8	919.4	925.9	947.4	982.6	1122.4	978.6	930.3	1016.2	1010.7	997.1	1073.2	1010.8	1041.4	1079.4

	Iguacu											Ribeira	Litoranea	
Year	65-010-000	65-025-000	65-035-000	65-060-000	65-310-000	65-895-002	65-993-000	65-175-000	65-260-000	65-825-000	65-960-000	81-200-000	82-170-000	82-195-000
1974	830.5	883.4	867.5	875.3	775.8	767.6	788.2	693.6	734.3	589.7	896.4	559.9		
1975	570.2	593.1	685.2	763.1	948.9	929.9	1074.8	965.7	1049.7	763.6	1254.8	795.1		
1976	606.7	733.5	815.8	895.3	898.4	934.7	974.6	997.5	472.5	966.5	999.6	881.9		
1977	746.9	711.5	896.7	983.7	1020.2	1038.3	1090.7	1084.6	896.8	949.0	1211.3	690.9		
1978	687.8	764.3	874.9	913.5	875.0	997.0	941.7	870.5	785.5	925.5	934.5	716.6		
1979	806.3	766.4	893.2	919.2	966.6	1032.0	1222.3	909.5	1061.0	1059.7	1096.8	952.8		
1980	908.5	845.2	1009.0	1092.0	1089.8	1227.8	1201.1	1127.1	800.4	1125.2	1034.9	909.6		
1981	652.6	642.0	736.4	757.5	764.9	900.4	1005.0	740.2	771.8	1084.0	1055.4	712.5		
1982	894.8	871.1	990.7	958.9	987.9	888.0	1134.8	1104.0	736.8	904.8	1100.4	1152.5		
1983	920.8	979.7	835.7	1060.3	1007.4	763.6	1145.4	984.5	864.1	943.4	854.1	872.1		
1984	860.1	758.0	774.7	937.0	910.2	1051.2	1149.8	864.1	768.7	1251.2	1131.2	780.0		
1985	671.2	638.1	689.6	723.8	729.4	757.3	795.2	748.7	678.9	820.2	932.1	469.5		
1986	1134.1	1119.0	1122.0	1132.2	1072.1	1147.4	1243.7	1057.8	908.3	1292.1	1130.7	1072.5		
1987	655.0	682.0	712.0	728.7	812.1	920.5	1069.3	802.1	757.7	904.0	1048.7	743.0		
1988	899.4	814.8	753.2	734.7	701.1	789.0	873.6	542.9	617.6	728.8	885.9	889.3		
1989	932.6	863.8	862.0	888.0	871.6	1032.7	1151.8	717.1	914.8	1223.4	1075.5	921.5		
1990	965.2	483.9	842.6	891.9	908.8	937.6	1208.7	840.5	865.7	874.8	1207.9	925.2		
1991	825.3	711.3	872.1	934.3	877.4	1024.5	1095.9	891.0	677.7	1394.4	1050.4	700.1		
1992	789.9	847.9	887.0	951.5	863.7	801.0	1096.6	952.0	835.5	1043.5	970.3	890.0		
1993	962.5	926.4	960.0	1034.3	1327.4	1303.9	1310.5	1085.8	1877.1	1109.3	1016.9	1011.8		
Mean	816.0	781.8	854.0	908.8	920.4	960.3	1078.3	899.0	853.7	997.6	1044.4	832.3	792.2	653.1

Table-2.10 Results of Computed Annual Mean Potential Evapotranspiration Depth

Mean Evapotranspiration Depth by Stations

Unit : (mm/year)

Year	Itarare	Cinzas		Tibagi				Pirapo	Ivai					Piquin			
	64-242-000	64-360-000	64-370-000	64-444-000	64-465-000	64-491-000	64-507-011	64-550-000	64-625-000	64-645-000	64-675-002	64-685-000	64-693-000	64-771-500	64-795-000	64-820-000	64-830-000
1974	931.6	949.3	1011.1	985.7	976.7	937.3	931.0	739.0	908.1	915.0	920.4	924.8	943.4	1114.2	1237.9	1210.7	1191.6
1975	896.0	957.9	1017.7	913.6	917.1	905.1	918.3	800.0	897.7	925.8	950.2	963.6	983.9	1043.0	1192.9	1184.1	1180.9
1976	911.3	924.9	968.8	959.9	961.0	939.6	944.5	1030.3	893.1	900.7	947.6	964.3	984.5	974.5	1009.0	1030.3	1064.1
1977	970.2	1090.8	1124.7	1011.0	1033.7	1052.6	1062.5	1117.1	935.5	957.9	1018.2	1035.8	1056.1	1014.3	1046.0	1072.5	1097.7
1978	1008.3	1143.2	1167.2	1067.7	1094.4	1118.2	1132.4	1177.7	1031.0	1063.7	1111.5	1128.1	1148.4	1116.1	1147.2	1173.0	1179.5
1979	942.2	1074.3	1103.0	997.6	1022.8	1045.0	1056.4	1092.1	967.0	986.6	1019.4	1035.0	1054.1	1022.9	1039.9	1064.5	1096.5
1980	983.9	1070.2	1099.0	984.3	1007.6	1032.2	1047.0	1099.2	970.7	991.2	1023.3	1038.1	1056.7	1022.6	1049.6	1070.1	1110.5
1981	964.0	1092.1	1123.4	982.1	1008.6	1036.5	1051.6	1097.2	955.5	979.3	1019.0	1033.3	1051.3	997.6	1045.8	1067.7	1099.9
1982	944.9	1019.6	1049.4	958.7	981.0	1003.2	1017.7	1073.3	940.5	959.1	996.1	1011.1	1029.6	996.9	1025.4	1047.3	1092.5
1983	923.6	1014.0	1053.4	931.5	950.2	966.3	980.7	1043.8	904.2	920.2	957.7	971.7	989.8	946.2	974.1	997.1	1078.7
1984	1038.7	1127.7	1176.4	1008.1	1035.4	1064.4	1098.5	1147.2	1011.7	1084.2	1115.7	1121.4	1131.0	1017.9	1056.0	1083.5	1127.1
1985	1054.1	1148.0	1199.1	1056.2	1080.7	1102.1	1155.3	1182.6	1103.7	1220.8	1231.3	1228.8	1229.7	1076.0	1112.0	1141.4	1149.3
1986	992.4	1073.7	1116.4	999.2	1019.5	1035.4	1077.9	1095.2	1020.7	1110.1	1129.3	1129.7	1134.1	1024.3	1073.1	1095.8	1126.9
1987	1014.6	1089.1	1128.7	990.3	1012.9	1034.2	1076.6	1091.9	1019.2	1106.5	1120.9	1121.6	1124.4	1009.1	1044.8	1069.1	1099.0
1988	1202.3	1215.6	1293.5	1056.4	1067.5	1079.5	1125.3	1305.4	1077.6	1136.6	1221.9	1243.1	1270.1	1231.8	1304.0	1327.1	1328.7
1989	1205.7	1177.8	1237.2	1014.8	1027.9	1048.0	1080.7	1157.5	1029.4	1080.5	1153.6	1168.5	1188.8	1194.6	1298.3	1305.0	1333.7
1990	1136.4	1207.7	1286.4	991.4	1004.5	1019.1	1062.0	1191.9	1012.0	1064.8	1123.0	1146.0	1175.0	1120.5	1160.8	1196.2	1229.7
1991	1149.3	1251.4	1314.6	1082.2	1094.3	1104.0	1140.9	1253.3	1099.3	1155.7	1206.8	1229.0	1258.3	1225.7	1266.4	1299.6	1339.8
1992	1081.4	1187.7	1242.5	1023.0	1036.2	1049.9	1085.5	1173.8	1037.8	1090.1	1138.4	1156.8	1183.0	1139.8	1177.7	1211.0	1260.6
1993	1069.5	1188.2	1242.3	1049.3	1057.7	1062.8	1095.1	1177.4	1059.1	1099.8	1143.6	1165.4	1191.4	1150.1	1143.4	1187.5	1228.1
Mean	1021.0	1100.2	1147.7	1003.1	1019.5	1031.8	1057.0	1102.3	993.7	1037.4	1077.4	1090.8	1109.2	1071.9	1120.2	1141.7	1170.7

Year	Iguacu											Ribeira	Litoranea	
	65-010-000	65-025-000	65-035-000	65-060-000	65-310-000	65-895-002	65-993-000	65-175-000	65-260-000	65-825-000	65-960-000	81-200-000	82-170-000	82-195-002
1974	871.6	905.9	936.8	944.7	954.0	948.0	932.6	994.1	955.1	986.6	908.8	947.8	842.3	817.3
1975	835.9	868.1	880.0	878.5	861.1	874.0	893.2	899.0	825.7	977.4	887.6	888.8	802.7	772.1
1976	897.5	944.0	958.5	948.8	923.7	915.6	911.9	981.7	879.6	1000.2	876.6	950.0	847.5	803.2
1977	939.3	982.7	998.1	991.9	944.3	935.1	949.6	1023.2	844.6	989.2	946.7	982.6	882.6	852.8
1978	967.5	1015.9	1041.4	1041.8	1008.9	1037.9	1018.6	1087.0	927.9	1130.0	1011.5	1027.9	906.6	877.5
1979	832.0	848.6	901.9	928.8	910.4	912.0	903.6	1006.2	809.6	1087.9	882.3	944.1	827.3	834.2
1980	832.7	838.4	884.9	911.0	901.1	909.4	909.9	976.2	824.4	1084.5	890.7	969.3	838.9	854.3
1981	832.3	846.1	891.7	915.1	900.4	900.1	899.0	980.5	817.4	1055.7	885.0	948.0	831.2	835.2
1982	806.6	811.4	858.7	885.2	881.1	888.7	890.8	951.7	816.5	1054.0	884.1	941.8	809.9	831.0
1983	776.9	787.7	832.3	857.7	790.0	801.4	836.1	919.5	585.2	1003.0	865.9	905.7	781.1	785.8
1984	854.7	864.6	916.2	941.7	865.2	878.1	912.8	1017.8	635.6	1082.0	920.2	1011.6	864.7	870.8
1985	873.3	885.6	946.5	979.5	963.0	981.5	999.9	1066.7	853.9	1154.1	1007.5	1035.3	879.1	891.0
1986	850.9	850.5	900.8	927.7	912.0	928.1	951.2	1000.4	818.1	1070.2	970.5	978.5	864.7	889.0
1987	835.3	840.6	891.0	918.1	908.6	927.1	944.0	990.3	828.7	1080.4	960.4	988.5	845.5	860.8
1988	925.4	938.4	958.0	973.3	1004.3	1056.4	1120.4	993.5	1053.6	1120.1	1186.4	1117.1	914.4	910.3
1989	936.1	938.9	957.2	966.7	978.8	1012.4	1058.6	992.0	989.2	1066.8	1095.8	1121.2	935.9	943.1
1990	934.3	938.7	951.1	954.1	965.3	999.7	1036.3	973.6	985.6	1061.5	1087.6	1038.5	930.0	933.0
1991	984.3	987.5	1009.7	1023.1	1051.6	1095.1	1147.0	1051.9	1092.3	1135.4	1192.7	1075.2	958.5	993.0
1992	952.4	957.4	974.2	983.1	990.9	1026.1	1076.7	1006.2	992.2	1055.2	1139.9	1014.7	947.3	953.4
1993	970.8	976.9	990.0	1000.1	1001.7	1033.8	1073.3	1014.3	990.5	1070.6	1136.6	1010.6	968.3	966.6
Mean	885.5	901.4	933.9	948.5	935.8	951.6	973.0	996.3	876.3	1063.2	986.8	994.9	873.9	873.7

2.3.2 Runoff Ratio

Using the annual rainfall depth and annual surface runoff over the same catchment area, surface runoff volume and surface runoff ratio by stations were summarized in Table-2.9. The simulation period was applied the last 20 years(1974-1993), and Figure-2.8 shows relation between catchment area and runoff ratio.

Based on Table-2.11, Figure-2.9, runoff ratio at all basins except for Litoranea basin ranges from 30 to 50 % with a mean of 41 %, and Litoranea basin ranges from 69 to 80 % because the riverbed profile has a steep slope as shown in Figure-2.10. Especially, runoff ratio at some reference points in Tibagi, Cinzas and Pirapo basins shows at the ranges from 30 to 40 %, because high evapotranspiration condition as compared with other basins.

Table-2.11 Summary of Mean Annual Surface Runoff Ratio

(Simulation Period : 1974 - 1993, 20 Years)

Basin	River	No.	St. No.	St.Name	Area (km2)	Rainfall (mm/year)	Runoff (mm/year)	Balance (mm/year)	Runoff Ratio
Itarare	Jaguariaiva	1	64-242-000	Tamandua	1,622	1335.4	632.4	703.0	0.47
Cinzas	Cinzas	2	64-360-000	Tomazina	2,015	1491.3	565.8	925.4	0.38
		3	64-370-000	Andira	5,622	1440.3	480.5	959.8	0.33
Tibagi	Tibagi	4	64-444-000	Uvaia	4,450	1560.2	640.7	919.4	0.41
		5	64-465-000	Tibagi	8,948	1565.7	639.8	925.9	0.41
		6	64-491-000	Barra Rib.das Antas	15,600	1569.7	622.3	947.4	0.40
		7	64-507-011	Jataizinho (Extendido)	21,955	1587.6	604.9	982.6	0.38
Pirapo	Pirapo	8	64-550-000	Vila Silva Jardim	4,627	1615.2	492.7	1122.4	0.31
Ivai	Ivai	9	64-625-000	Tereza Cristina	3,572	1694.5	715.8	978.6	0.42
		10	64-645-000	Porto Espanhol	8,600	1659.9	729.7	930.3	0.44
		11	64-675-002	Porto Bananeiras	24,200	1665.1	648.9	1016.2	0.39
		12	64-685-000	Porto Paraiso do Norte	28,427	1657.6	646.9	1010.7	0.39
		13	64-693-000	Novo Porto Taquara	34,432	1642.2	645.1	997.1	0.39
Piquiri	Piquiri	14	64-771-500	Porto Guarani	4,223	1928.9	855.6	1073.2	0.44
		15	64-795-000	Ponte do Piquiri	11,303	1936.9	926.2	1010.8	0.48
		16	64-820-000	Porto Formosa	17,500	1865.1	823.7	1041.4	0.44
		17	64-830-000	Balsa do Santa Maria	20,982	1843.0	763.6	1079.4	0.41
Iguacu	Iguacu	18	65-010-000	Fazendinha	110	1557.3	741.2	816.0	0.48
		19	65-025-000	Guajuvira	2,304	1416.5	634.8	781.8	0.45
		20	65-035-000	Porto Amazonas	3,662	1445.9	591.8	854.0	0.41
		21	65-060-000	Sao Mateus do Sul	6,065	1483.6	574.8	908.8	0.39
		22	65-310-000	Uniao da Vitoria	24,211	1584.2	663.8	920.4	0.42
		23	65-895-002	Salto Osorio	45,824	1725.6	765.3	960.3	0.44
		24	65-993-000	Salto Cataratas	67,317	1802.9	724.7	1078.3	0.40
	Negro	25	65-175-000	Divisa	7,970	1515.9	616.9	899.0	0.41
	Timbo	26	65-260-000	Foz do Cachoeira	693	1738.7	884.9	853.7	0.51
	Jordao	27	65-825-000	Santa Clara	3,913	1893.4	895.8	997.6	0.47
	Chopim	28	65-960-000	Aguas do Vere	6,696	2003.2	958.8	1044.4	0.48
Ribeira	Ribeira	29	81-200-000	Capela do Ribeira	7,252	1378.1	545.8	832.3	0.40
Litoranea	Nhundiaquara	30	82-170-000	Morretes	217	*) 2537.7	1745.5	792.2	0.69
	Marumbi	31	82-195-002	Morretes	53	*) 3300.0	2646.9	653.1	0.80
Mean	All Basins					1723.9	787.9	936.0	46%
						100%	*46%*	*54%*	
	Basins except for Litoranea Area					1641.5	690.8	950.7	42%
						100%	*42%*	*58%*	

Note : *) : It was determined by using an existing Iso-hyetal Map (COPEL)

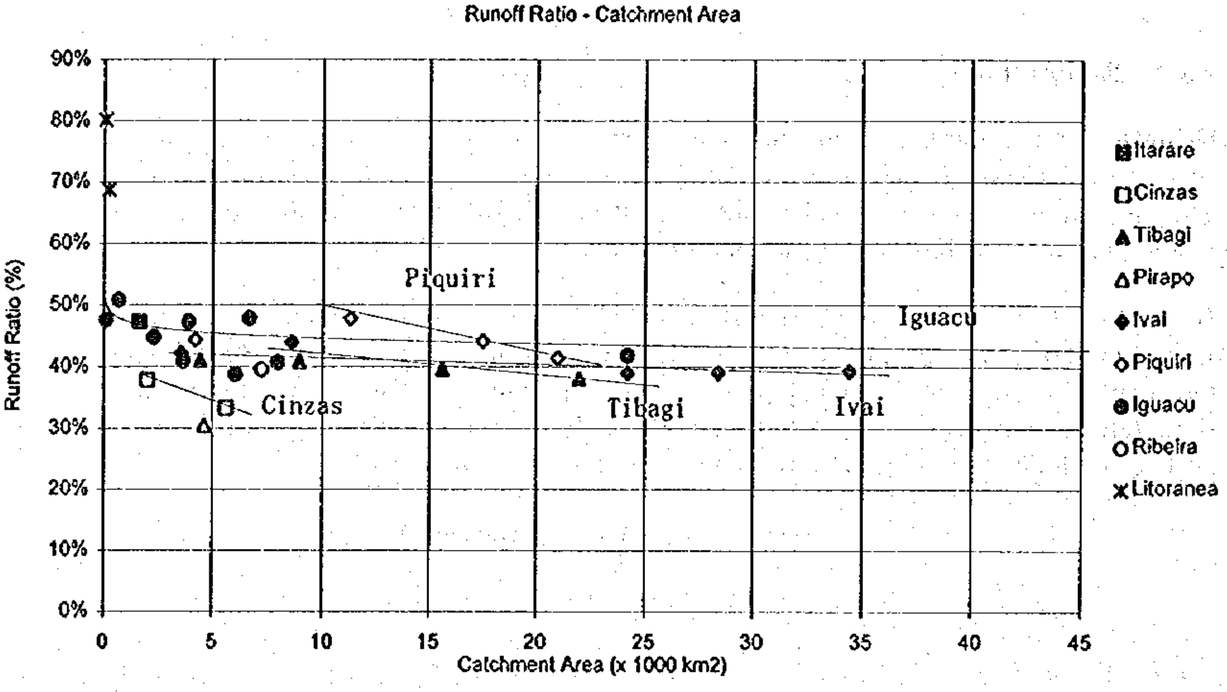

Figure-2.9 Relations between Catchment area and Runoff Ratio

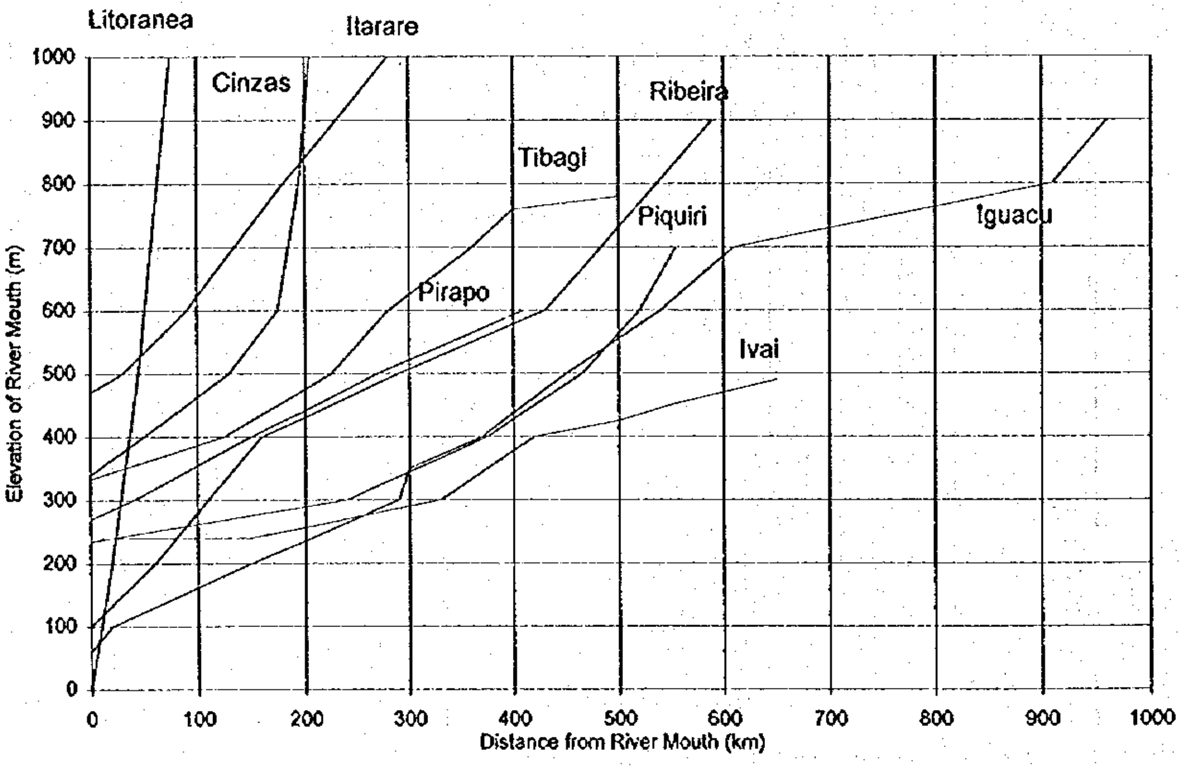

Figure-2.10 Riverbed Profile by Basin

2.3.3 Actual Evapotranspiration

(1) Results of Analysis

Although there are lack of data availability and researches concerning actual evapotranspiration in Parana, the following assumption was made to characterize the actual evapotranspiration in this Study.

Figure-2.11 shows the relation between annual rainfall and annual runoff depth at all selected stations with same period, and it shows that the ratio of annual runoff depth to annual rainfall depth increases or decreases whether rainfall is less or more than 1,500 mm/year respectively.

In case of using individual river basin which has constant rainfall distribution through the year, the relation between annual rainfall and annual runoff depth is clearly observed on a plotting graph.

Furthermore, by plotting the amount of annual actual evapotranspiration as shown in Figure-2.12, the relationship between annual actual evapotranspiration and annual rainfall is described as follows;

- The amount of annual actual evapotranspiration varies proportionally with the amount of annual rainfall, but the amount of annual evapotranspiration does not increase when the annual rainfall is at the upper range of 1,500 mm/year. It means that the amount of annual evapotranspiration varies inversely when the amount of annual rainfall exceeds 1,500 mm/year.
- The amount of annual evapotranspiration decreases gradually when annual rainfall exceeds about 1,500 mm, because conditions happen a shortage of insolation volume.

By assuming a ratio between annual actual evapotranspiration by water balance method (:Evta) and annual potential evapotranspiration by using Penman's equation (:Evt), actual evapotranspiration at each catchment area has been calculated in this Study (Refer to Figure-2.13).

Based on Figure-2.13, when annual rainfall is less than 1,500 mm/year, the ratio of Evta/Evt varies from 0.4 to 0.9, with a mean of 0.7, and when annual rainfall exceeds 1,500 mm/year, the ratio varies from 0.8 to 1.3, with a mean of 0.9. Table-2.12 shows a summary of the mean of Evta/Evt ratio for the last 20 years.

(2) Consideration

Although various types of meteorological data are measured at many stations in Parana, evaporation is measured only at several stations and evapotranspiration is not measured in the state.

Evaporation and evapotranspiration are vital factors in analysis of hydrological cycle and in formulation of water resources development plan. Continuous measurement of evaporation and evapotranspiration will be necessary for more precise analyses and planning in the future.

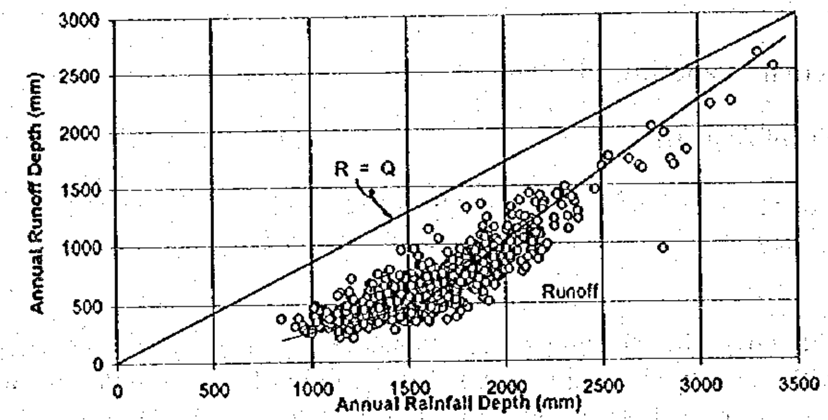

Figure-2.11 Relation between Annual Rainfall and Annual Runoff
(Simulation period : 1974 - 1993, 20 Years)

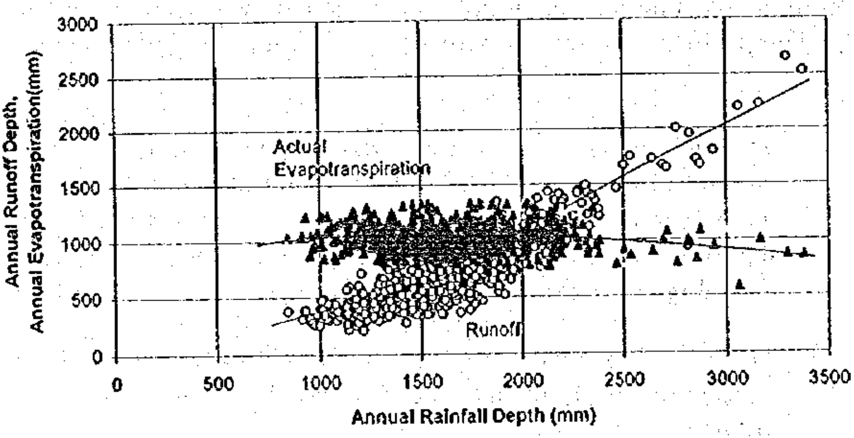

Figure-2.12 Relation between Annual Rainfall and Annual Actual Evapotranspiration
(Simulation period : 1974 - 1993, 20 Years)

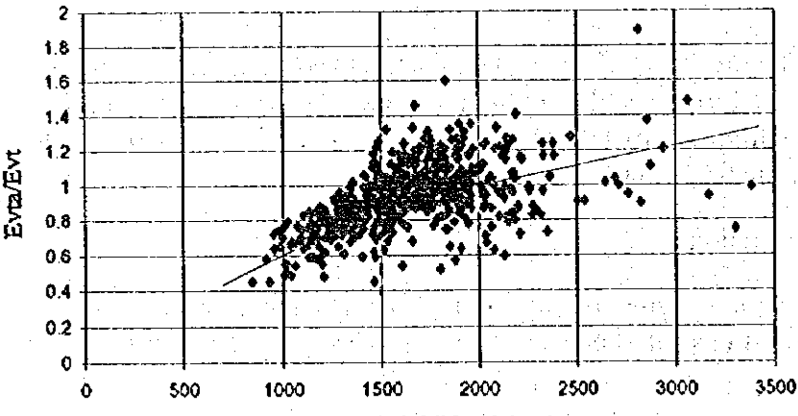

Figure-2.13 Relation of Annual Rainfall and Evta/Evt Ratio
(Simulation period : 1974 - 1993, 20 Years)

Table-2.12 Summary of Evta/Evt Ratio (1974-1993, 20 Years)

Basin	River	No	St. No.	St.Name	Area (km2)	Rainfall (mm/year	Runoff (mm/Year)	Evapotranspiration (mm/year)		Ratio of
								Evta	Evt	Evta/Evt
Itarare	Jaguariaiva	1	64-242-000	Tamandua	1,622	1335.4	632.4	703.0	1021.0	0.6
Cinzas	Cinzas	2	64-360-000	Tomazina	2,015	1491.3	565.8	925.4	1100.2	0.8
		3	64-370-000	Andira	5,622	1440.3	480.5	959.8	1147.7	0.8
Tibagi	Tibagi	4	64-444-000	Uvaia	4,450	1560.2	640.7	919.4	1003.1	0.9
		5	64-465-000	Tibagi	8,948	1565.7	639.8	925.9	1019.5	0.9
		6	64-491-000	Barra Rib.das Antas	15,600	1569.7	622.3	947.4	1031.8	0.9
		7	64-507-011	Jataizinho (Extendido)	21,955	1587.6	604.9	982.6	1057.0	0.9
Pirapo	Pirapo	8	64-550-000	Vila Silva Jardim	4,627	1615.2	492.7	1122.4	1102.3	1.0
Ival	Ival	9	64-625-000	Tereza Cristina	3,572	1694.5	715.8	978.6	993.7	0.9
		10	64-645-000	Porto Espanhol	8,600	1659.9	729.7	930.3	1037.4	0.9
		11	64-675-002	Porto Bananeiras	24,200	1665.1	648.9	1016.2	1077.4	0.9
		12	64-685-000	Porto Paraiso do Norte	28,427	1657.6	646.9	1010.7	1090.8	0.9
		13	64-693-000	Novo Porto Taquara	34,432	1642.2	645.1	997.1	1109.2	0.9
Piquiri	Piquiri	14	64-771-500	Porto Guarani	4,223	1928.9	855.6	1073.2	1071.9	1.0
		15	64-795-000	Ponte do Piquiri	11,303	1936.9	926.2	1010.8	1120.2	0.9
		16	64-820-000	Porto Formosa	17,500	1865.1	823.7	1041.4	1141.7	0.9
		17	64-830-000	Balsa do Santa Maria	20,982	1843.0	763.6	1079.4	1170.7	0.9
Iguacu	Iguacu	18	65-010-000	Fazendinha	110	1557.3	741.2	816.0	885.5	0.9
		19	65-025-000	Guajuvira	2,304	1416.5	634.8	781.8	901.4	0.8
		20	65-035-000	Porto Amazonas	3,662	1445.9	591.8	854.0	933.9	0.9
		21	65-060-000	Sao Mateus do Sul	6,065	1483.6	574.8	908.8	948.5	0.9
		22	65-310-000	Uniao da Vitoria	24,211	1584.2	663.8	920.4	935.8	0.9
		23	65-895-002	Salto Osorio	45,824	1725.6	765.3	960.3	951.6	1.0
		24	65-993-000	Salto Cataratas	67,317	1802.9	724.7	1078.3	973.0	1.1
	Negro	25	65-175-000	Divisa	7,970	1515.9	616.9	899.0	996.3	0.9
	Timbo	26	65-260-000	Foz do Cachoeira	693	1738.7	884.9	853.7	876.3	0.9
	Jordao	27	65-825-000	Santa Clara	3,913	1893.4	895.8	997.6	1063.2	0.9
	Chopim	28	65-960-000	Aguas do Vere	6,696	2003.2	958.8	1044.4	986.8	1.0
Ribeira	Ribeira	29	81-200-000	Capela do Ribeira	7,252	1378.1	545.8	832.3	994.9	0.8
Litoranea	Nhundiaquara	30	82-170-000	Morretes	217	*) 2537.7	1745.5	792.2	873.9	0.9
	Marumbi	31	82-195-002	Morretes	53	*) 3300.0	2646.9	653.1	873.7	0.7
Mean	All Basins					1723.9	787.9	936.0	1015.8	0.9
						100%	*46%*	*54%*	-	-
	Basins except for Litoranea Area					1641.5	690.8	950.7	1025.6	0.9
						100%	*42%*	*58%*	-	-

Note : *) : It was determined by using an existing Iso-hyetal Map (COPEL)

CHAPTER 3 SURFACE WATER RESOUCES

3.1 Criteria

3.1.1 River Water Development Criteria

The existing criteria for river water development in Parana State are described as follows;

<Water Resources Grant Criteria> *(IAP)*

1) For surface water resources utilization, the following conditions should be taken into account, considering the existing and forecasted uses:

   Q_{out} < is less than $0.5 \times Q_{10,7}$

   where,

   Q_{out} = granted discharge by direct intake

   $Q_{10,7}$ = Low water flow which happens once in 10 years and lasts 7 days.

a) There can not be a case where an intake discharge lower than $0.5\ Q_{10,7}$ occurs downstream of intake point.

b) For the existing intakes, which do not follows the criteria above, it must be considered the following :

Public Water Supply :	The utilization will be allowed if within grant time validity, the maximum of five (5) years
Other Uses :	The utilization will be allowed if within grant time validity, the maximum of two (2) years.

2) For water resources utilization with regulation works, the downstream discharge must have a maximum of $0.5\ Q_{10,7}$, respecting users demand at downstream of existing dam.

3) The public supply grant must also obey a minimum utilization limit due to imposed restrictions for potentially pollutants above the intake sections, considering the following conditions:

   $Q_{out} > 0.1\ Q_{10,7}$

a) For the existing intakes, which are not following the patterns above, the utilization will be allowed within a grant time validity of the maximum of five (5) years.

b) The extension to the above conditions, the intake basins with an area of $\geq 50\ km^2$.

4) Grants will only be conferred when the intended use will be compatible to the quality standard of water established in CONAMA Resolution number : 20/86 and State Law number : 8935/89.

a) For public supply cases in operation which do not follow the standard water quality pattern mentioned above, it will be allow a grant time validity of the maximum of five (5) years.

5) Grants and / or Environmental licenses for potentially new polluters in intake basin for public supply, which do not obey the criteria, or in intake basins with an area of < 50 km^2 will not be conceded.

In the case of irrigation, a case be case analysis will be carried out for intake basins with a superior area of 50 km^2.

3.1.2 Maintenance Discharge Criteria

(1) Low Maintenance Discharge ($Q_{10,7}$ and Q_{355})

Index of low maintenance discharge adopted in Brazil is $Q_{10,7}$ (refer to section 3.1.1).

In the Parana State (CEHPAR, 1982), by processing discharge data of 57 observation stations, 6 coefficient contour maps are prepared, so that $Q_{10,7}$ at every point on the map can be roughly estimated by calculating by applying 6 coefficients obtained from the map with some limitations.

On the other hand, index of low water adopted in Japan is Q_{355} which is the 355th daily discharge from greatest daily discharge (refer to the flow regime mentioned in section 2.2.3). The minimum of Q_{355} during 10 years, or the second minimum of Q_{355} during 20 years, seems to be equal to the low water flow with occurrence probability of once in 10 years.

Comparison between $Q_{10,7}$ and the second minimum of Q_{355} during the 20 years was made in the specific discharge, based on the observation data of 31 stations mentioned in section 2.2.3, as shown in Table - 3.1 and Figure - 3.1.

Although the relation between them is different station by station, average of 31 stations almost same as $0{,}3m^3 / sec / 100\ km^2$ for both discharges.

(2) Maintenance Discharge

In the Parana State, the maintenance discharge including water use downstream is stipulated to be more than 50% of $Q_{10,7}$.

$Q_{10,7}$ is the flow which happens once in 10 years and the least average discharge during continuous 7 days. $Q_{10,7}$ at each discharge point in Parana has been establishing as HG 52. Probable computation for HG 52 is adapted existing 57 hydrological stations of which catchment area has less than 5,000 km^2, and determine a relationship between a return period (:TR) and a continuous day (: t). Using the determined relationships, the following value such as reproduce period (TR), continuous day (t) and mean discharge ($Q_{TR,t}$) are able to compute by using equations.

$$q_t = \exp[a + b \cdot l_n t + c(l_n t)^2]$$

$$u_{TR} = \alpha + (\beta - \alpha)[-l_n(1 - \frac{1}{TR})]^{1/\gamma}$$

$$Q_{TR,t} = \frac{A}{1{,}000} \cdot u_{TR} \times q_t$$

where,

a,b,c,α,β,γ are constant values depends on point to be determined, and 6 kinds of isoparametic curves are given in HG 52.

Specific maintenance discharge of 31 observation stations vary from 0.05 to 0.3 m^3/sec/100 km^2 and the average is almost 0.15 m^3/sec/100 km^2.

In Japan, the maintenance discharge is determined considering required water for keeping picturesque scenery, preservation of ecosystem, securing cleanliness of river flow, inland navigation, fishing, etc. However, generally the specific discharge should be about the average of Q_{355} during 10 years, and at least more than 0.3 m^3/sec/100 km^2. Therefore, specific maintenance discharge is almost two times that of Parana State.

However, since the most of water resources development in Japan depend on regulated flow, by dam / reservoir, and the maintenance discharge with specific discharge of 0.3 m^3/sec/100 km^2 flow most of year except for case of large scale flooding, the total amount of maintenance discharge in the Parana State might be more than in Japan. In Japan it is stipulated that the normal discharge composed of maintenance discharge and water use downstream is to be discharged by the upstream dam / reservoirs.

3.1.3 Surface Development Criteria

In the Study the following criteria were adopted considering that they are stipulated in the Law of the Parana State.

1) Allowable direct intake water should be less than 50% of $Q_{10,7}$.

2) Maintenance discharge should be more than 50% of $Q_{10,7}$.

For reference in Japan, most of water resources development projects by dam / reservoir are planned so that the newly developed water can be obtained every year except for once in 10 years or twice in 20 years. Results of computed $Q_{10,7}$ by the selected station are referred to Appendix-3.

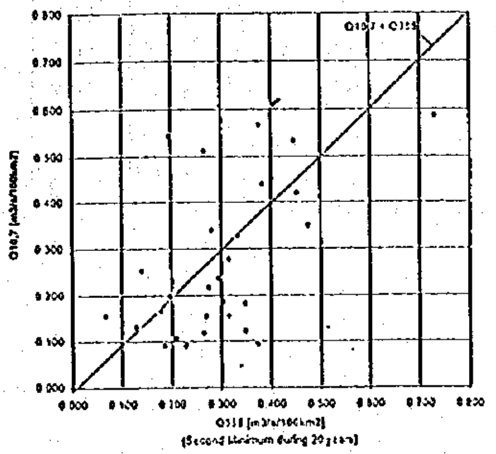

Figure-3.1 Relation between Min. Q_{355} and $Q_{10,7}$

Table-3.1 Comparison betweeen $Q_{10,7}$ and Q_{355}

No.	River	Station Name	C. A.	Q_{ave}		Q_{355}		$Q_{10,7}$	
			km^2	m^3/sec.	/100km^2	m^3/sec.	/100km^2	m^3/sec.	/100km^2
1	Itarare	Tamandua	1622	32.49	2.003	7.69	0.474	5.68	0.350
2	Cinzas	Tomazina	2015	35.94	1.784	7.02	0.348	3.67	0.182
3		Andira	5622	87.33	1.553	11.77	0.209	6.07	0.108
4	Tibagi	Uvaia	4450	90.60	2.036	13.59	0.305	8.28	0.186
5		Tibagi	8948	126.97	1.419	17.80	0.199	14.05	0.157
6		Barra Rib. das Antas	15600	307.86	1.973	42.09	0.270	24.18	0.155
7		Jatalzinho (Extendido)	21955	421.55	1.920	50.50	0.230	19.98	0.091
8	Pirapo	Vila Silva Jardin	4627	72.24	1.561	18.55	0.401	20.82	0.450
9	Ival	Tereza Cristina	3572	81.23	2.274	4.59	0.128	4.75	0.133
10		Porto Espanhol	8600	199.48	2.320	16.00	0.186	7.74	0.090
11		Porto Bananeiras	24200	492.85	2.037	43.19	0.178	40.41	0.167
12		Porto Paraiso do Norte	28427	583.73	2.053	76.00	0.267	145.55	0.512
13		Novo Porto Taquara	34432	703.32	2.043	155.39	0.451	144.96	0.421
14	Piquiri	Porto Guarani	4223	115.49	2.735	5.89	0.139	10.68	0.253
15		Ponte do Piquiri	11303	332.48	2.942	22.00	0.195	61.60	0.545
16		Porto Formosa	17500	457.10	2.612	66.03	0.377	99.40	0.568
17		Balsa do Santa Maria	20982	523.00	2.493	80.50	0.384	92.32	0.440
18	Iguacu	Fazendinha	110	2.59	2.355	0.49	0.445	0.59	0.536
19		Guajuriva	2304	47.77	2.073	6.78	0.294	5.46	0.237
20		Porto Amazonas	3662	68.84	1.880	7.19	0.196	7.32	0.200
21		Sao Mateus so Sul	6065	112.14	1.849	16.11	0.266	7.16	0.118
22		Uniao da Vitoria	24211	518.32	2.141	68.05	0.281	82.32	0.340
23		Salto Osorio	45824	1068.81	2.332	126.00	0.275	99.44	0.217
24		Salto Cataratas	67317	1443.69	2.145	213.00	0.316	187.14	0.278
25		Divisa	7970	154.75	1.942	27.85	0.349	9.80	0.123
26		Foz do Cachoeira	693	18.88	2.724	2.59	0.374	0.64	0.092
27		Santa Clara	3913	111.21	2.842	13.09	0.335	12.83	0.328
28		Aguas do Vere	6696	197.63	2.951	21.19	0.316	10.45	0.156
29	Ribeira	Capela do Ribeira	7252	125.50	1.731	52.94	0.730	42.56	0.587
30	Litoranea	Morretes (Nhundiaquara)	217	12.02	5.539	0.88	0.406	1.33	0.613
31		Morretes (Marumbi)	53	4.57	8.623	0.22	0.415	0.33	0.623
	Average				2.480		0.314		

Note: Q_{355} is the second minimum during 20 years.

3.2 Current Water Use

3.2.1 General

At present, domestic water for urban area is supplied to 98% of urban population. SANEPAR supplies water to 89% of urban population and other organizations, including municipalities, supply the rest.

Water source depends on surface water in 85%, and groundwater in 15%. The areas where the percentage of surface water is high are Iguacu, Tibagi, Cinzas and Litoranea river basins, and use of groundwater prevails in Parana residual basins and Paranapanema residual basins.

3.2.2 Data Collection

According to information and data on water use are scattered among related organizations and types of registration form are also different. To understand the present situation of water use, the following data collection were carried out.

(1) Data Availability

To collect the available existing data on water use, the Team made investigations through the following related organizations.

1) EMATER

EMATER company is constituted by one directorate, 20 regional offices and 23 district offices. It is responsible for the technical assistance in agriculture. According to information from EMATER head office, registration of irrigation is only available as named SISCON (National Irrigation Database) obtained by National Irrigation Secretary in Ministry of Agriculture. In addition to above data collection, interviews to 42 municipal offices were made by the Team. SISCON database is covered 1,484 registers.

2) IAP

IAP is composed of 5 directorates such as Administrative and Financial, Juridical, Inspection and Licensing Environmental Information, and Technical and Scientific Directorates. Date were collected mainly from Inspection and Licensing Directorate (DIFLA) which is composed of two departments such as Department of Diffusion of Environmental Information (DEFAM) and Department of Environmental Statistics (DELAM).

a) DEFAM(Department of Diffusion of Environmental Information)

DEFAM is responsible for the authorization of water use from the available water sources. The existing data of 1,680 registered companies are available at present.

b) DELAM(Department of Environmental Statistics)

DELAM is responsible for the authorization of installation and operation by private companies. The existing data of 1,299 registered companies are available.

The water supply sources are usually used by own, not only from SANEPAR water supply system.

(3) SANEPAR

Data from SANEPAR is available with 1,820 registered water supply systems, and it is in a database of DEFAM.

(4) COPEL

Data from COPEL is available with 113 registered hydroelectric stations.

(5) Interview and Questionnaire Survey

The Team made a interview and questionnaire survey for branch offices of IAP, EMATER and SANEPAR, and 190 municipalities.

After processing the collected data, the database system was prepared as shown in Figure-3.2.

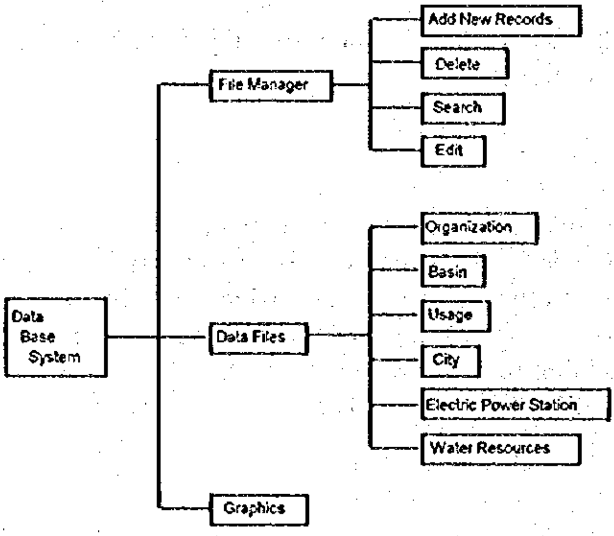

Figure-3.2 Database System of Water Use

3.2.3 Results of Current Water Use Survey

The collected data and information are summarized as the following water supply categories;

- Public supply
- Industrial supply
- Irrigation supply
- Mining supply
- Pisciculture supply
- Leisure (recreation) supply
- Services supply
- Other utilities supply

An amount of water supply by category and basin are summarized as shown in Table - 3.2, and a distribution of main water supply categories such as public water supply, industrial water supply, irrigation water supply and others by basin is shown in Figure - 3.3.

There is a difference between the required supply water volume estimated by the Study Team and the results of above current water use survey. The main reason is that the results of current water use survey were summarized to collect for the water use which already registered as a water right.

Especially, agriculture water both the results differ remarkably, because the operated duration time of water supply by day or season is limited. Although the required supply water was determined by considering the operated duration time, the results of current water use survey were adapted to determine as a continued 24 hours operation time.

Therefore, the amount of required water supply volume computed by the Study Team is appropriated for the current water use conditions.

Table-3.2 Amount of Water Supply by Category and by Basin

Unit : m3/sec

Name of Basin	Required Supply Water Amount				Current Water Use Supply					
	Domestic	Industrial	Agricult.	Total	Domestic	Industrial	Agricult.	Mining	Others	Total
CINZAS	0.331	0.099	0.307	0.737	0.853	0.292	1.152	0.003	0.016	2.316
IGUACU	7.773	3.650	0.635	12.058	9.453	1.916	1.194	0.000	0.014	12.577
ITARARE	0.234	0.087	0.049	0.370	0.330	0.139	0.001	0.000	0.003	0.473
IVAI	2.255	0.420	0.459	3.135	2.033	3.321	3.637	0.001	0.009	9.001
LITORANEA	0.393	0.035	0.007	0.435	1.543	0.008	0.707	0.006	0.000	2.264
PARANA-1	0.928	0.002	0.025	0.955	0.146	0.007	0.000	0.000	0.000	0.153
PARANA-2	0.081	0.005	0.054	0.140	0.208	0.003	0.068	0.000	0.000	0.279
PARANA-3	1.340	0.465	0.147	1.952	1.643	0.133	2.015	0.000	0.000	3.791
PARANAPANEMA-1	0.190	0.045	0.017	0.252	0.205	0.055	0.702	0.006	0.000	0.968
PARANAPANEMA-2	0.046	0.010	0.007	0.063	0.014	0.000	0.631	0.000	0.000	0.645
PARANAPANEMA-3	0.353	0.099	0.057	0.509	0.283	0.068	1.556	0.000	0.000	1.907
PARANAPANEMA-4	0.171	0.019	0.077	0.267	0.217	0.028	0.000	0.003	0.000	0.248
PIQUIRI	1.333	0.244	0.316	1.893	1.291	0.394	1.436	0.000	0.001	3.121
PIRAPO	0.896	0.299	0.084	1.279	1.190	0.151	1.763	0.007	0.004	3.115
RIBEIRA	0.283	0.095	0.045	0.423	0.367	0.011	0.001	0.047	0.000	0.426
TIBAGI	2.745	0.958	0.201	3.904	4.826	0.613	1.649	0.001	0.009	7.168
Total	18.790	6.532	2.290	27.612	24.443	5.439	13.802	0.074	0.056	43.876

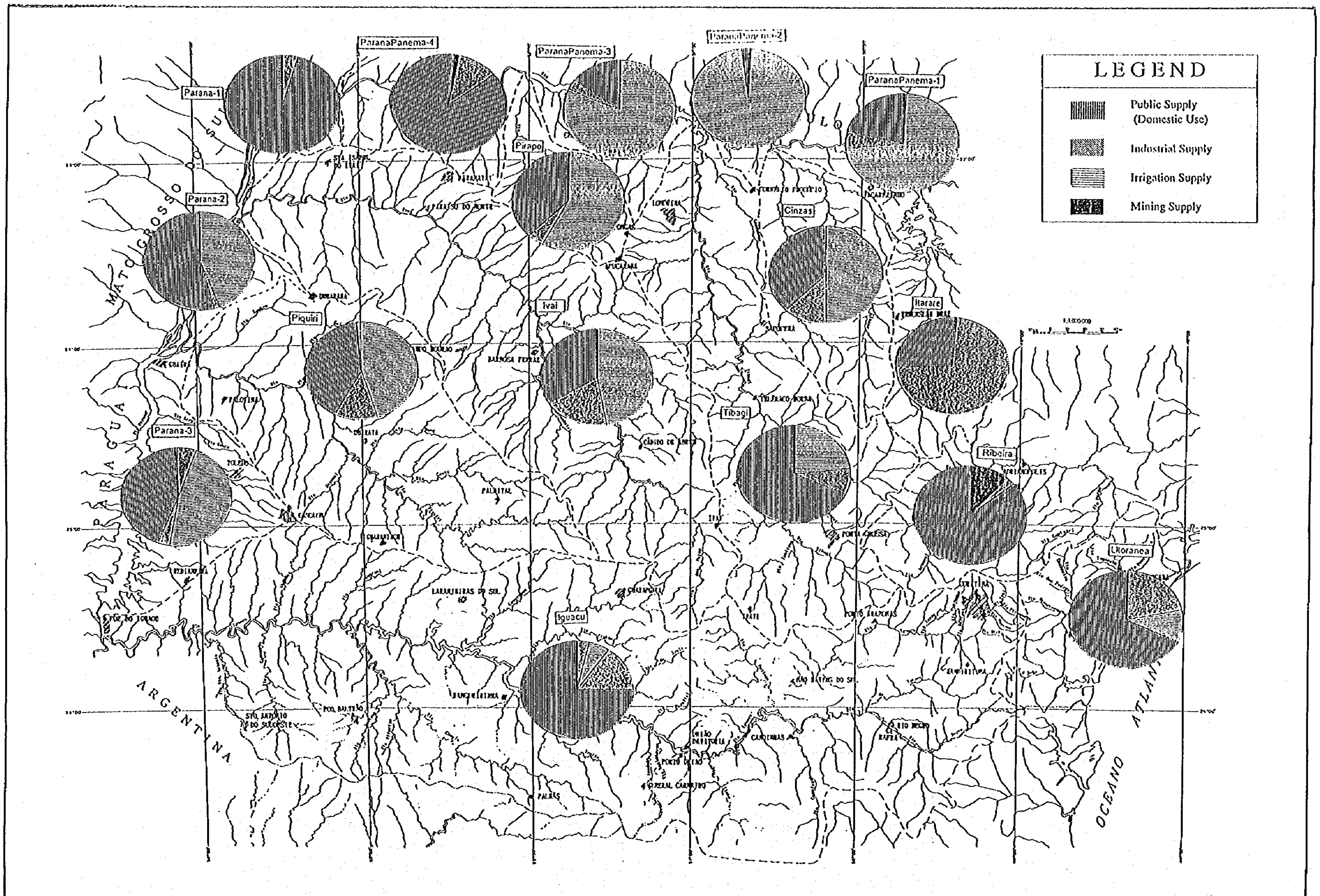

Figure-3.3. Distribution of Water Supply Use by Basin

3.3 Surface Water Potential for Each Basin

Applying the mentioned water development and maintenance discharge criteria (refer to the section 3.1), an amount of surface water potential by discharge reference point was computed as follows;

(1) Discharge Reference Point

Each river basin was divided into maximum 5 blocks as shown in Figure - 3.4 for convenience of surface water development study mentioned later in Sectoral Report Vol. G. The boundary of each block crossing the river basin was determined along the boundary of the municipality as similar as possible to the natural boundary of tributary basins.

30 discharge reference points were determined downstream of each block. Surface water potential is to be calculated at discharge reference points.

(2) Surface Water Potential

Surface water potential was calculated by deducting maintenance discharge (0.5 $Q_{10,7}$) from the low water flow ($Q_{10,7}$, map obtained form CEHPAR (1982)) at each reference point. The water use of the upstream was not considered in the above calculation. The results are shown in Table - 3.3 and Figure - 3.4. The results of $Q_{10,7}$ at each point are shown in Appendix-3 of Data Book.

Table-3.3 Surface Water potential at Each Reference Point

No.	Basin	Block	Area	Potential
			(km2)	(m3/s)
(1)	Cinzas	CZ-1	1,970	1.789
(2)		CZ-2	9,291	4.945
(3)	Iguacu	IG-1	3,590	3.817
(4)		IG-2	18,300	20.827
(5)		IG-3	38,670	43.554
(6)		IG-4	57,000	60.115
(7)		IG-5	68,700	93.229
(8)	Itarare	IT-1	5,198	7.643
(9)	Ivai	IV-1	3,170	2.102
(10)		IV-2	8,442	3.812
(11)		IV-3	19,992	10.159
(12)		IV-4	29,206	72.997
(13)		IV-5	35,679	66.578
(14)	Litoranea	LT-1	5,766	20.045
(15)	Parana-1	PA-1	1,332	4.543
(16)	Parana-2	PA-2	3,157	5.416
(17)	Parana-3	PA-3	8,668	10.582
(18)	Parana Panema-1	PP-1	1,246	1.299
(19)	Parana Panema-2	PP-2	695	0.349
(20)	Parana Panema-3	PP-3	3,712	4.168
(21)	Parana Panema-4	PP-4	4,144	6.776
(22)	Piguiri	PQ-1	8,745	14.738
(23)		PQ-2	18,969	53.894
(24)		PQ-3	24,708	43.542
(25)	Pirapo	PR-1	5,006	8.833
(26)	Ribeira	RB-1	4,016	10.141
(27)		RB-2	9,129	25.937
(28)	Tibagi	TB-1	5,148	4.296
(29)		TB-2	16,475	12.760
(30)		TB-3	24,635	16.846

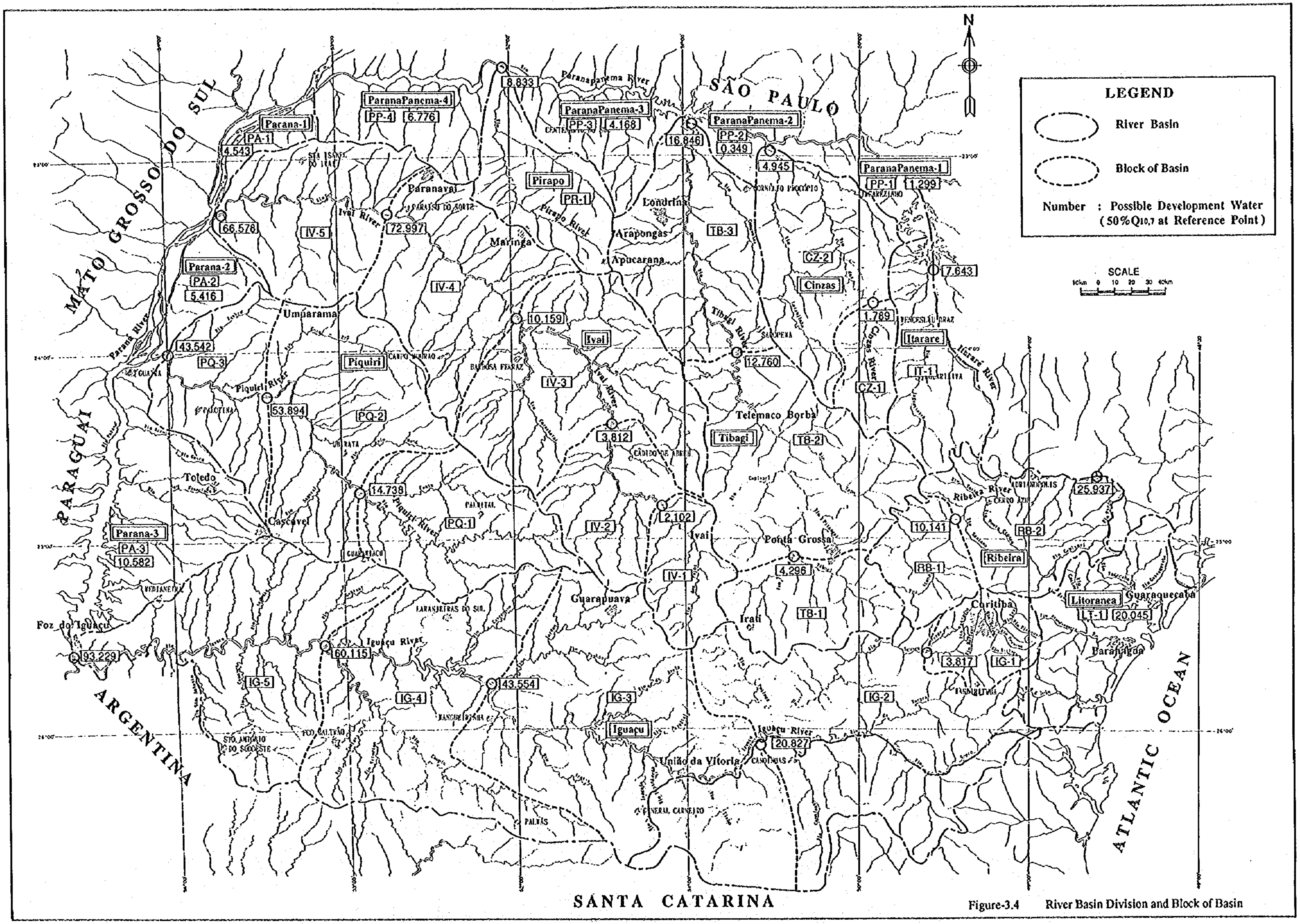

Figure-3.4 River Basin Division and Block of Basin

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APPENDICES

(refer to Data Book)

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