**Table-D.21 Water Discharge and Initial Water Depth (Mati River)**

| Case of Discharge | | Discharge Q (m3/sec) | Initial water depth hi=h0 (A0) (m) | Initial water level Hi (A0) (m) |
|---|---|---|---|---|
| ① | ⑤×0.2 | 46 | 1.382 | 1.502 |
| ② | ⑤×0.4 | 92 | 2.114 | 2.234 |
| ③ | ⑤×0.6 | 138 | 2.714 | 2.834 |
| ④ | Desingn | 170 | 3.087 | 3.207 |
| ⑤ | ⑤×0.8 | 184 | 3.199 | 3.319 |
| ⑥ | Desingn | 230 | 3.723 | 3.843 |
| ⑦ | ⑤×1.2 | 276 | 4.168 | 4.288 |
| ⑧ | ⑤×1.4 | 322 | 4.586 | 4.706 |

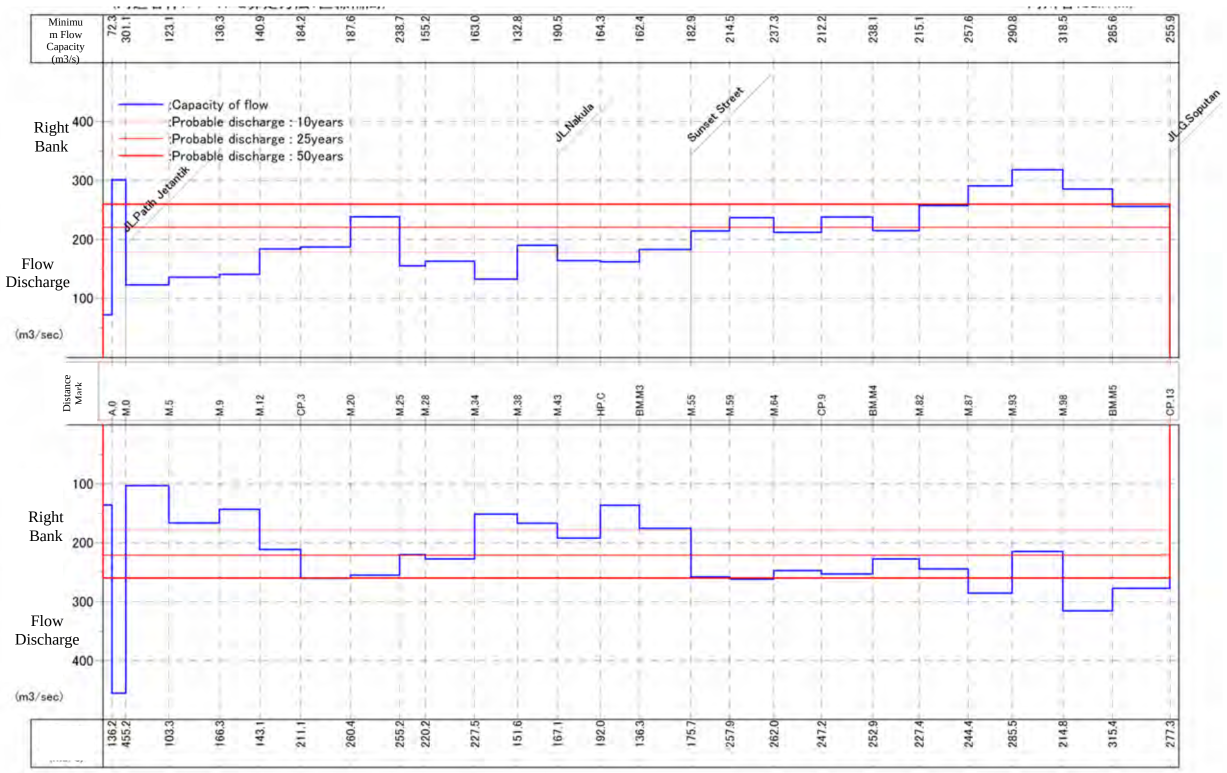



**Figure-D.25 Current River Flow Capacity of Mati River (River Mouth to Umadui Weir)**

## D-4.3 Mitigating Effects of Flood Damage by River Improvement

### D-4.3.1 Outline of River Improvement Plan

#### (1) Badung River

As regarding current condition of Badung River, masonry revetment, with the gradient ratio of 1:05 - 1:10, is installed on both river banks. Average river width is 23m, however river course with its width 20m or less is left at a bridge near B.K. Tunggal Street. It is a trench-type river and riverbed excavation, parapet placement and embankment were proposed in the cross section for the improvement plan discussed in 2001. River-widening, however, is difficult because of the density of housing, small factories and stores located along the river.

According to such conditions, riverbed excavation and parapet placement to bank based on the existing cross section will be operated. Gate of Buagan Weir currently in operation to irrigate paddy field located in the downstream will be renovated partly to secure the flow section.

**Table-D.22 Specification for River Improvement of Badung River**

| Items | Specifications | Remarks |
|---|---|---|
| 1) Section | Buagan Weir (downstream) to Gajah Mada St. (upstream) | 4,030 m is extended |
| 2) Design Flood | 205 m3/s | 220 m3/s in future |
| 3) Designed River Gradient | I=1/650 | |
| 4) River Width & Gradient of Revetment | Width=20-25m、Riverbed=14-20m (Revetment 1:0.5) | |
| 5) Adopted Works | Riverbed Excavation, Parapet Placement, Revetment, Buagan Weir Improvement | |

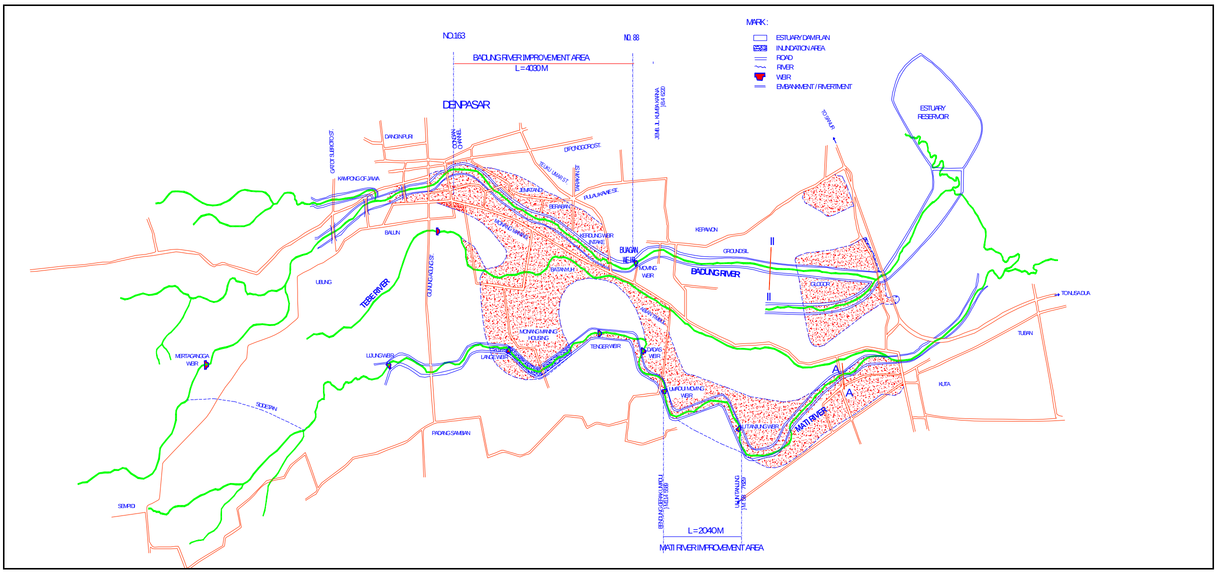



**Figure-D.26 Section for River Improvement (Badung and Mati River)**

Note: Section with distance of 4,030m from Buagan Weir in downstream (Distance Mark No.88-50) to Gajah Mada St. (Distance mark NO.151)

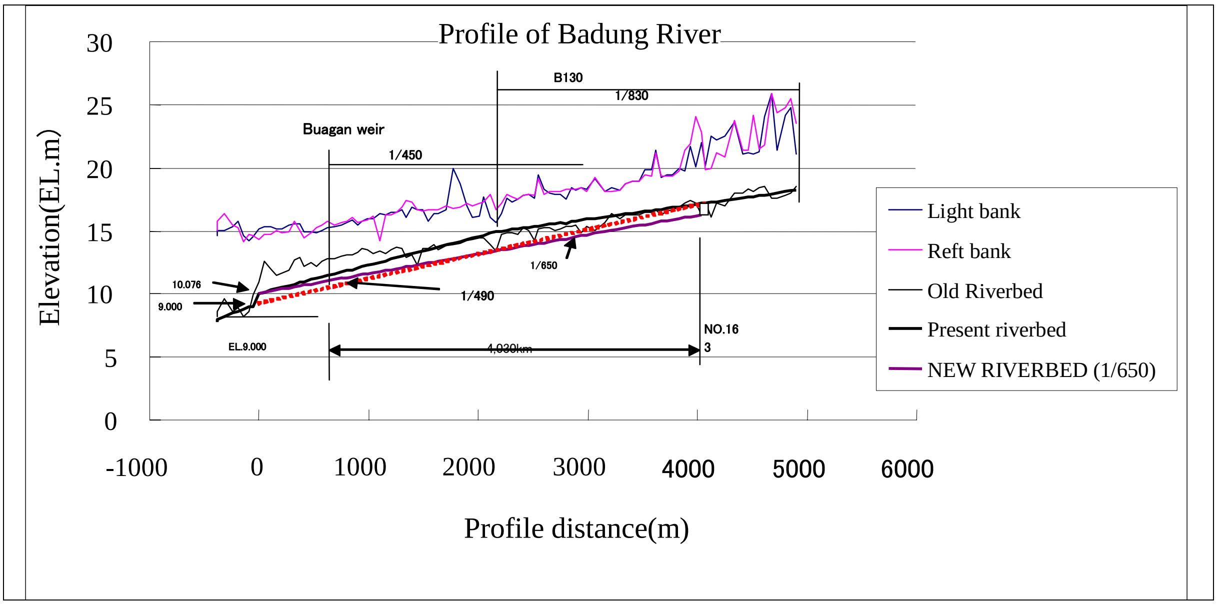



**Figure-D.27 Design Gradient of the Improvement Section for Badung River**

Note: Ground Sill (h=0.91m) is created at 4,000m upstream of Buagan Weir. Excavation will be operated between them. Design bed slope is 1/650.

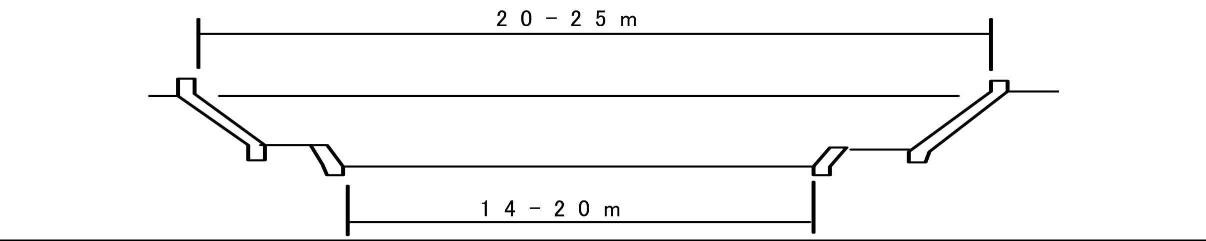



**Figure-D.28 Cross Section of Badung River**

Note: Parapets installation and excavation for low-waver channel with some bank improvement works will be operated.

### (2) Mati River

Although the area in the downstream is densely populated, river improvements including bank protection have already been completed. Flow capacity of designed 170m3/s is virtually secured. The section with the distance of 2,000m starting from Ulun taung Weir (upstream) to Umadui Weir (downstream) has not yet improved. Condition of Land use within this section is mostly paddy field or cropping land, most of which is temporarily in fallow.

Upadui Weir installed at the upper end of the section is needed to be retained since certain improvement of the facility has already been made. Ulun tanjung Weir in downstream, which is not currently in use, shall be removed.

Minimum flow capacity at the downstream of Ulun Tanjung Weir shall be adopted as design discharge and retarding basin will be installed to handle the amount exceeded capacity. Paddy lands and cropping fields shall be protected to secure the natural function of retarding basin.

**Table-D.23 Specifications of River Improvement Plan for Mati River**

| Items | Specifications | Remarks |
|---|---|---|
| 1) Section | Ulun Tanjung Weir (downstream) to Umadui Weir (upstream) | L=2,500 m |
| 2) Design Discharge (within the improvement section) | 170 $m^3$/s | Maintenance of Retarding Basin is included |
| 3) Designed River Gradient | I=1/1,000 | |
| 4) River Width & Gradient of Revetment | Width= 22-26.35 m (Revetment 1:0.5) | |
| 5) Adopted Works | Banking, River Widening, Removal of Ulun Tanjung Weir | |

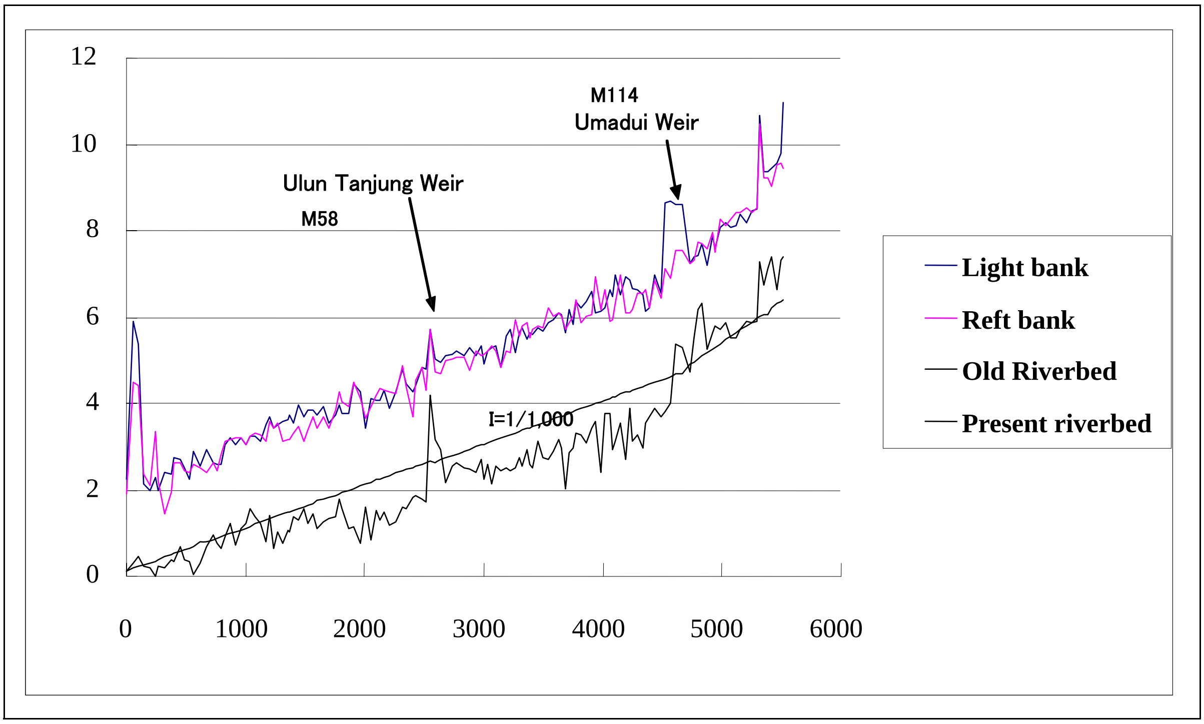



**Figure-D.29 Design Gradient of the Improvement Section for Mati River**

Note: Design bed slope is I=1/1,000 which is comparable to the current bed slope at the downstream of Umadui weir.

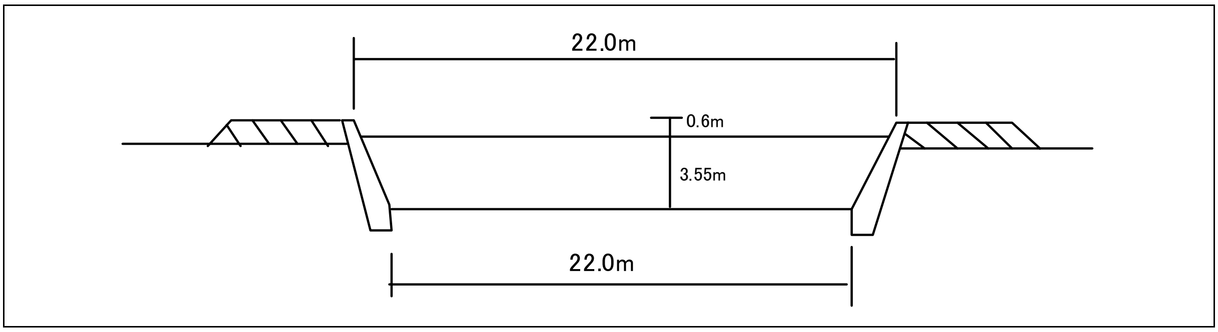



**Figure-D.30 Typical Cross Section of Mati River**

Note: River widening is to be operated to keep the cross-sectional area of flow.

### D-4.3.2 Mitigation of Flood Damage by River Improvement

To show the effects of river improvement work for flood control in Badung and Mati River, river level at the time of design flow discharge is calculated using non-uniform method.
The results are shown in Figure-D.33 and Figure-D.33.

Water level of Badung River with design discharge of 205m3/s will fall as the width of excavation broadened from 8m to10m. Some parts of the existing bank are lower than the river level but the problem can be solved by installing parapet.
Existing river channel of Mati river basically covers the water level with design discharge of 170m3/s; still, some parts with poor flow capacity are remained. Embankment and river widening works, however, will improve this problem.
To vilify the economic meaning of the river improvement project, expected flood area with the present condition was calculated using plain two-dimensional analysis model. The data shows the flood area with 25-year return period expands southwest toward the bypass; therefore, the improvement project for two rivers has an important role in mitigating the damage.

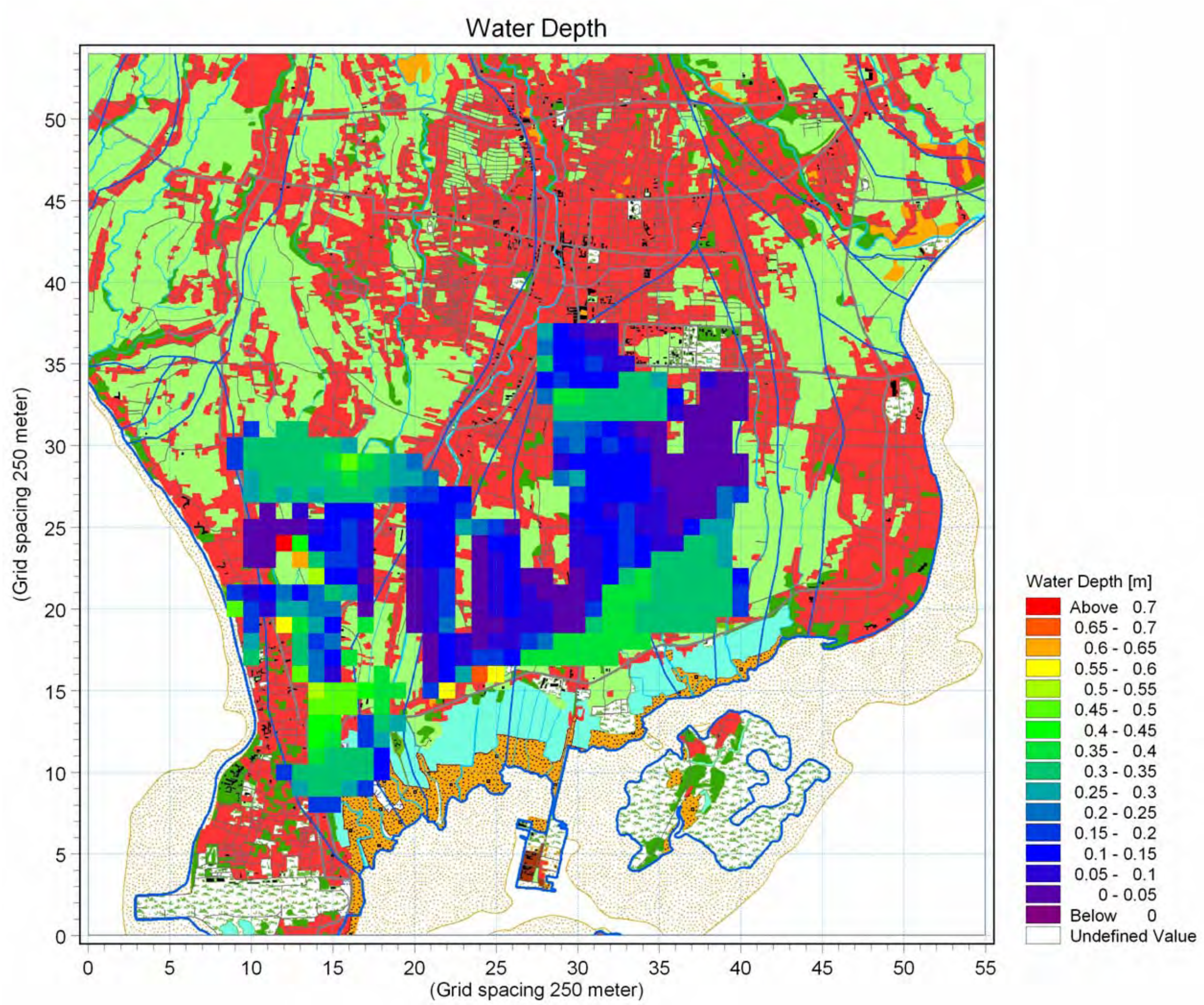



**Figure-D.31 Expected Flood Area before Improvement**

Conditions for Calculation

1) Condition of River Channel: Present 2) Return Period: 25yrs;
3) Flow Hydrograph: Centralized 4) Distance between Meshes：250m

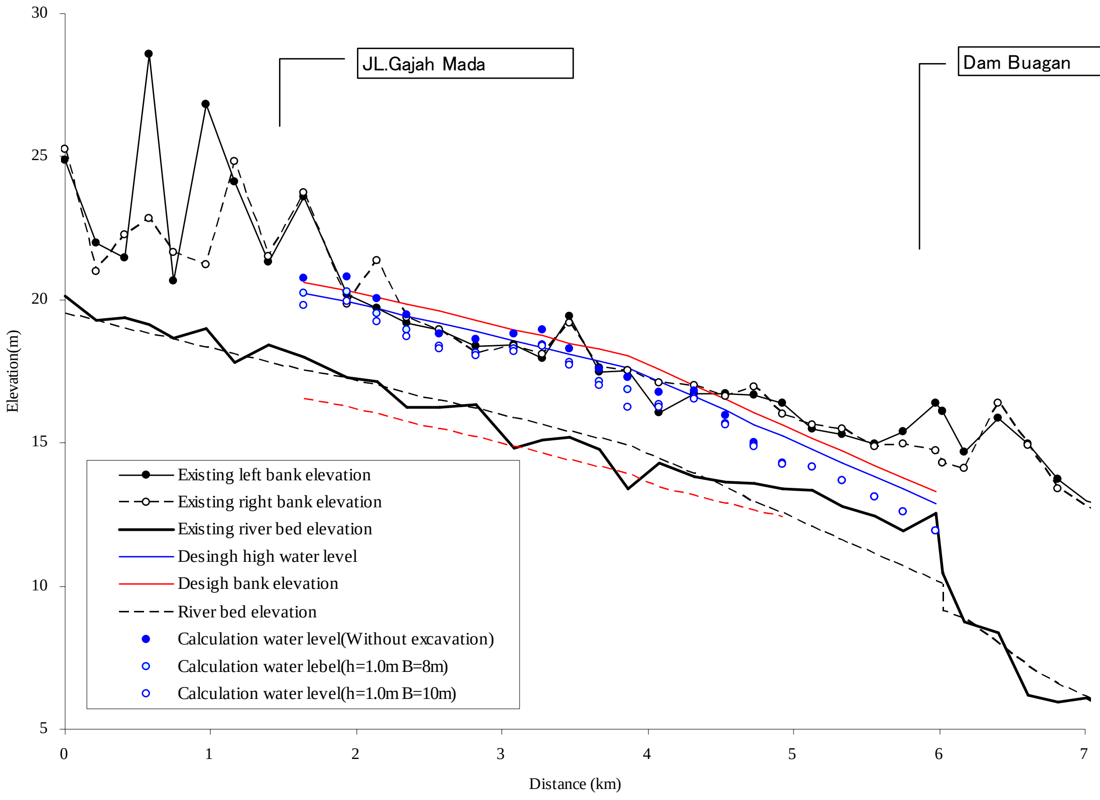



**Figure-D.32 Water Level with Design Discharge after River Improvement (Badung River)**

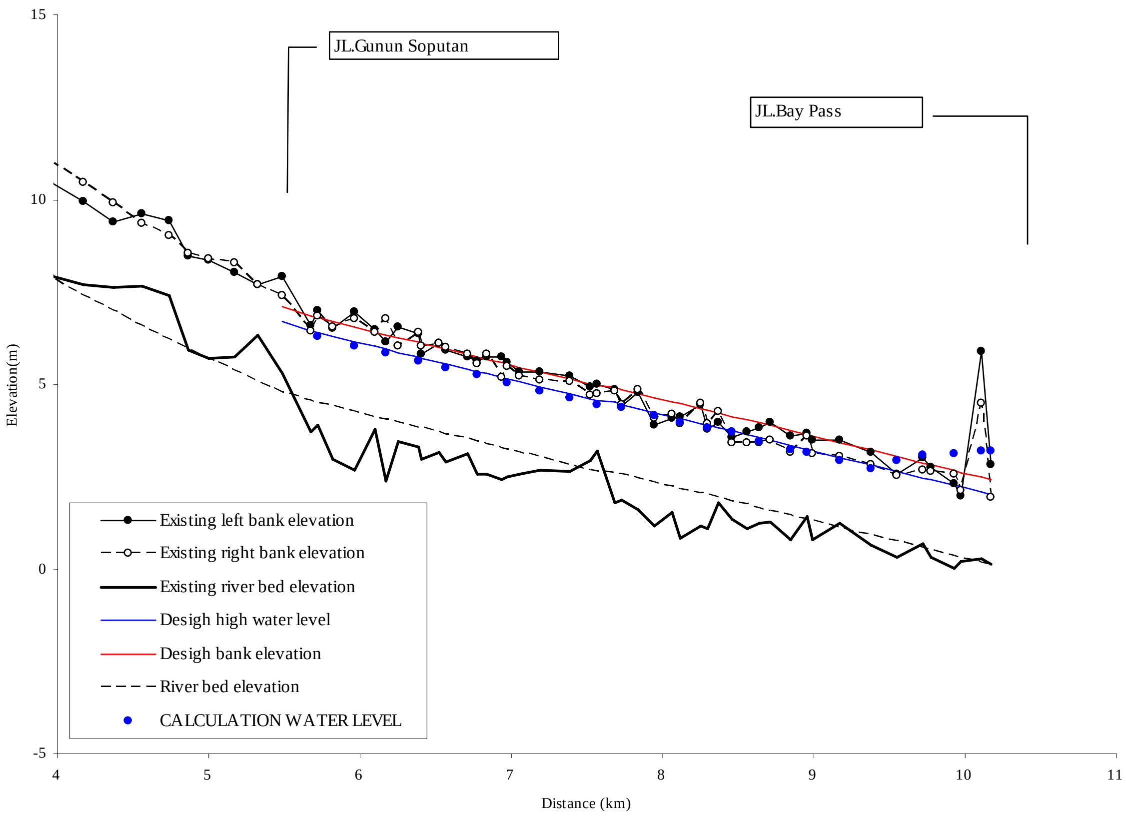



**Figure-D.33 Water Level with Design Discharge after River Improvement (Mati River)**

# D-5 FLOOD ANALYSIS BY MIKE FLOOD SYSTEM

## D-5.1 Outline of MIKEFLOOD System

MIKE_FLOOD system is consisted of MIKE11and MIKE21.

- MIKE11 : One-dimensional River Water Level Calculation Model (Unsteady Flow Calculation)
- MIKE21 : Flat Two-dimensional Water Level Calculation Model
- MIKE_FLOOD : Inundation Calculation Model

Procedure s for flood analysis is shown as follows:

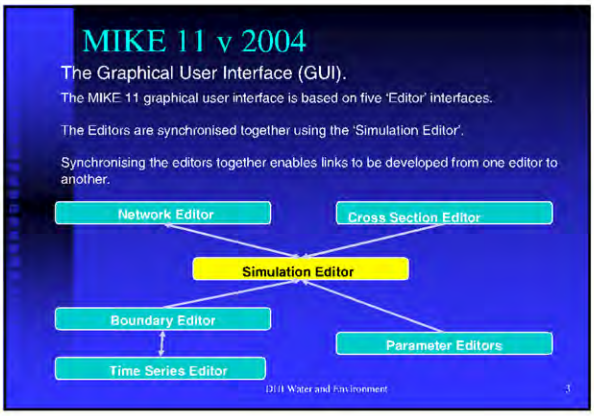
1) River water level calculation from hydrograph by MIKE 11
2) Division of mesh in inundation area and set up parameters as well as boundary conditions by MIKE21
3) Inundation Calculation for estimated inundation area by compiling outputs from MIKE11 and MIKE21
4) Calculation result of river water level can be seen as animation by MIKEVIEW

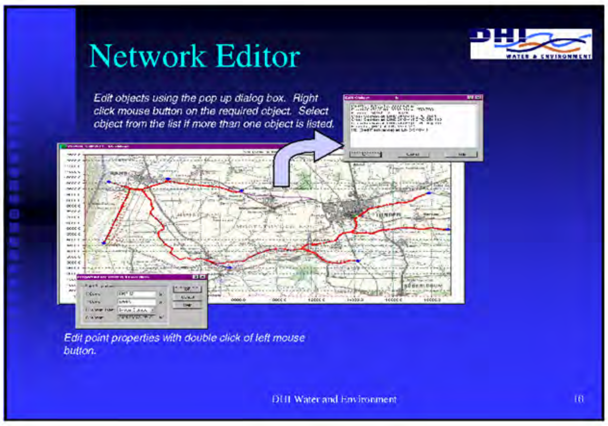
## D-5.2 MIKE11

Outline of MIKE11 summaries as follows:

**Table-D.24 General Outline of MIKE11**

| Name of Program | Functions | Work Description | Drawings or Data | Name of File |
|---|---|---|---|---|
| MIKE11 Network Editor | Edit of calculation points and shape of confluences for river tributaries | 1) Drawings of river plan with distance marks<br>2) Reading of drawings<br>3) Modeling of distance marks, boundary conditions and rivers on screen | • River Plan<br>• Cross Section<br>• Distance Marks, etc. | *.nwk11 |
| MIKE11 Cross Section Editor | Edit for each cross section | 1) Preparation of Cross Section<br>2) Arrangement of XY coordinates<br>3) Input of cross section data by editor | • Cross Section | *.xns11 |
| MIKE11 Boundary Editor | Set up boundary conditions. Discharge data shall be given for upstream boundary. Water Level for downstream boundary. | 1) Preparation for hydrograph and water level in river mouth<br>2) Input of calculation conditions and data by editor<br>3) Hourly data shall be input by 'Time series Editor' | • Hydrograph<br>• Water-level of River<br>• Mouth<br>• (Constant or Hourly) | *.bnd11 |
| MIKE11 Time series Editor | Set up hourly data of boundary | 1) Preparation for hydrograph and water level<br>2) input by editor | • Hydrograph<br>• Water-level of River Mouth (Constant or Hourly) | *.dfs |
| MIKE11 Parameter Editor | Set up parameter | 1) Preparation of roughness(n)<br>2) Input of calculation conditions and initial conditions | • Roughness(n) | *.HD11 |
| MIKE11 Simulation Editor | Execution program | 1) Reading input data shown as above.<br>2) Set up duration & time for calculation<br>3) Calculation *Blinking when some error occurred | | *.sim11 |



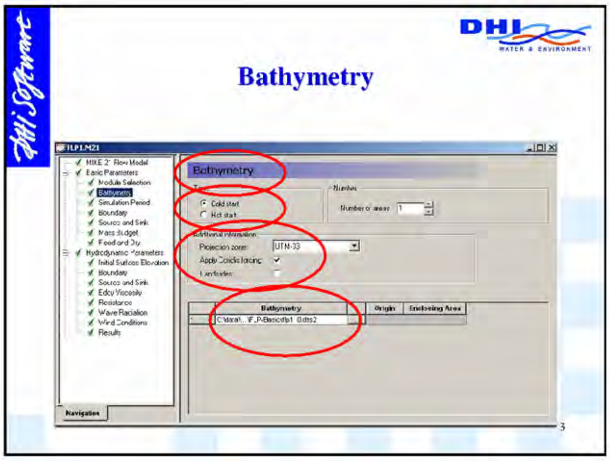



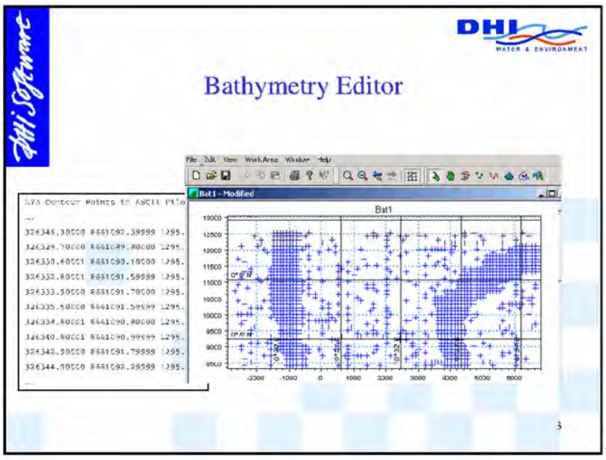

## D-5.3 MIKE21

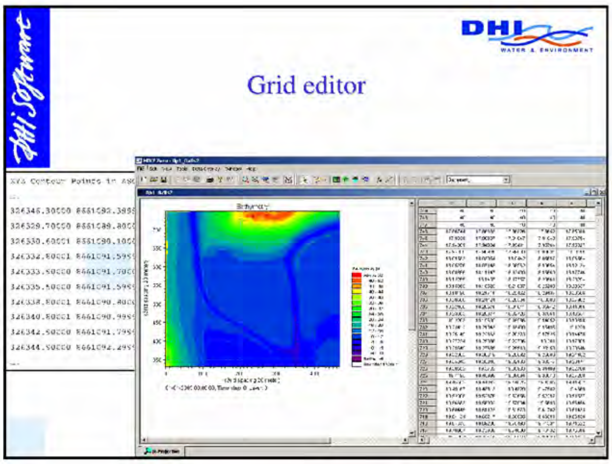
Outline of MIKE21 summaries as follows:

**Table-D.25 General Outline of MIKE21**

| Name of Program | Functions | Work Description | Drawings or Data | Name of File |
|---|---|---|---|---|
| MIKE ZERO bathymetry | Making a flat two-dimensional mesh data | 1) Making topographic map for study area. In case of electrical data based on GIS land use map, this data available for base map of calculation.<br>2) Decision for Simulation area. UTM Coordinates shall be adopted. To be needed for checking of river locations.<br>3) Automatic calculation of optional ground height based on designated ground height. (Refer to page 84)<br>4) Adjustment of data by Mesh Editor | • Topographic map<br>• Designated ground height in elevation<br>• Road height | *.dfs2 |
| MIKE21 | Flat two dimensional simulations between meshes. Discharge and water level are able to set in optional calculation points. | 1) Preparation of roughness(n)<br>2) Input of calculation conditions and initial conditions<br>3) Reading by designated （*.dfs2）<br>4) Calculation | • Roughness for each mesh<br>• Input data for boundary | *.m21 |



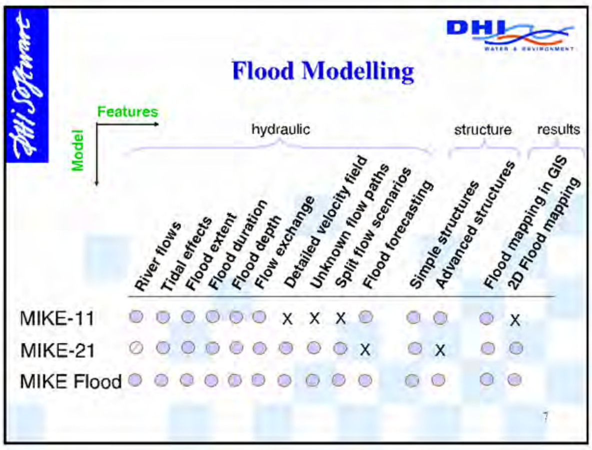



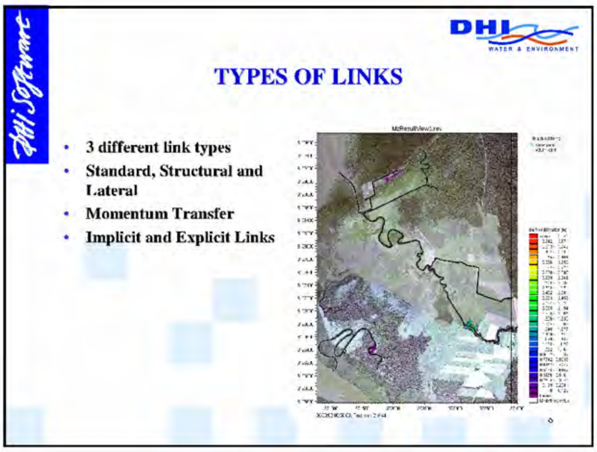

## D-5.4 MIKEFLOOD

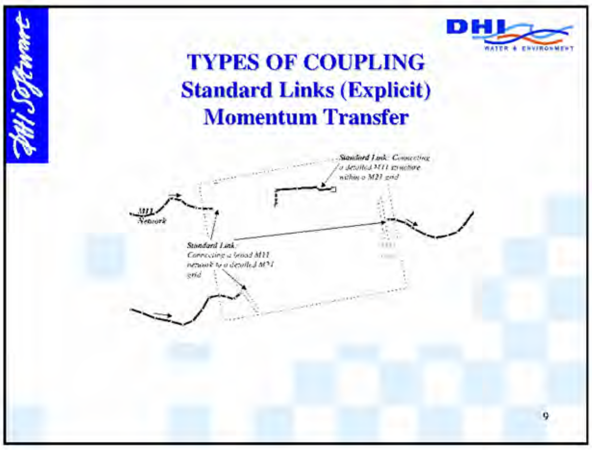
Outline of MIKEFLOOD shown as follows:

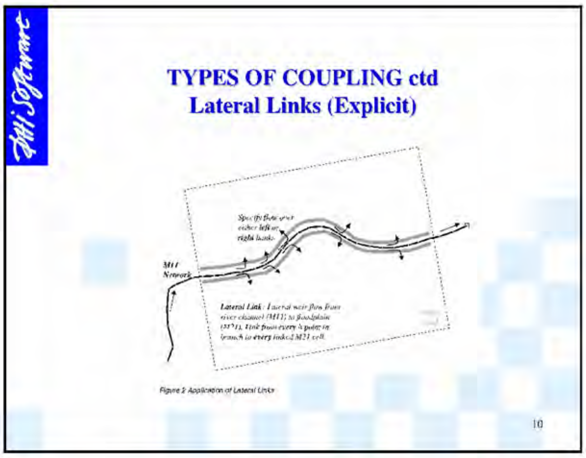
**Table-D.26 General Outline of MIKEFLOOD**

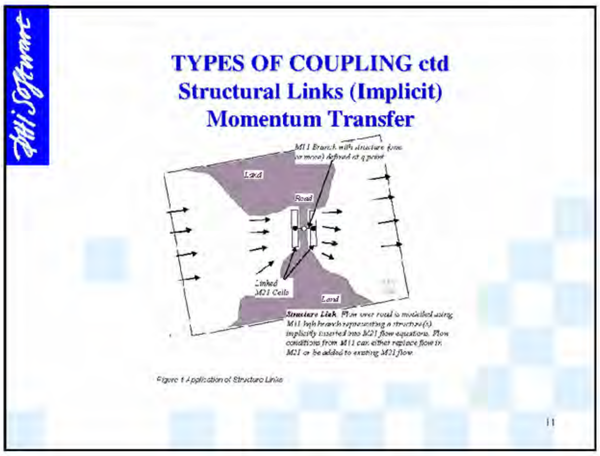
| Name of Program | Functions | Work Description | Remarks | Name of File |
|---|---|---|---|---|
| MIKE 11<br>MIKE Flood | 1) Built-in river model to flat two dimensional models.<br>2) Set up calculation conditions<br>3) Water level calculation in estimated inundation area | 1) Confirmation of file MIKE11and fileMIKE21<br>2) Call 2 files by 'Definition'<br>3) Arrangement of boundary conditions（3 kinds：Standard Links, Lateral Links, Structure Links）<br>Also built-in of boundary conditions.<br>Calculation | • How to give boundary conditions?<br>• Considerations for inundation patterns | *.couple |

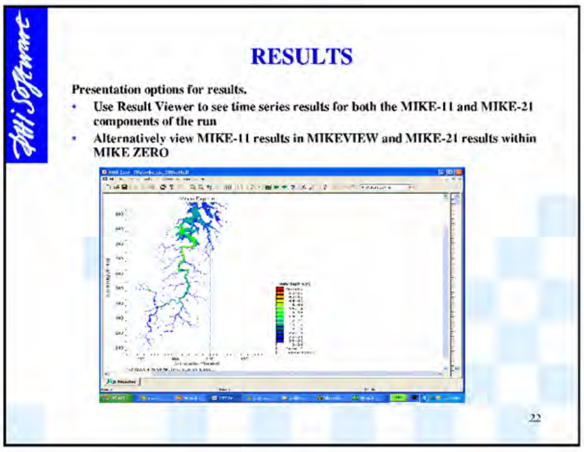




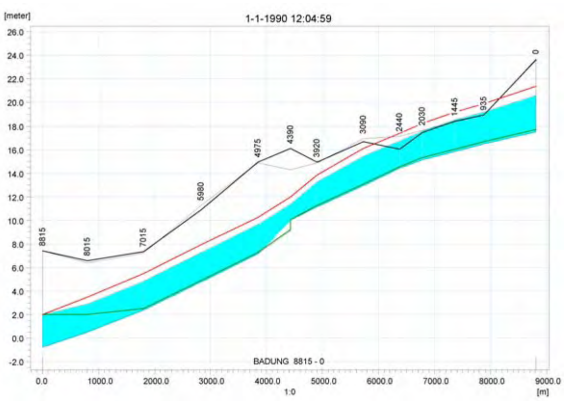



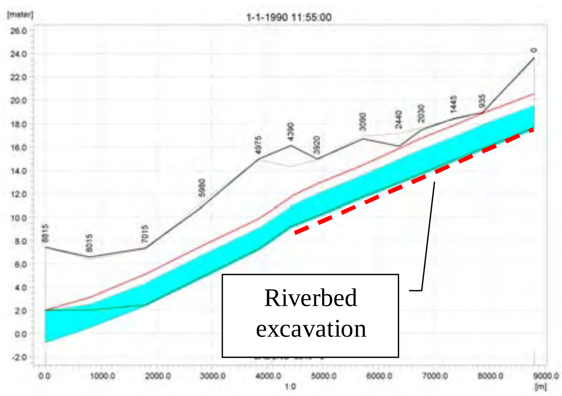




## D-5.5 Animation Functions

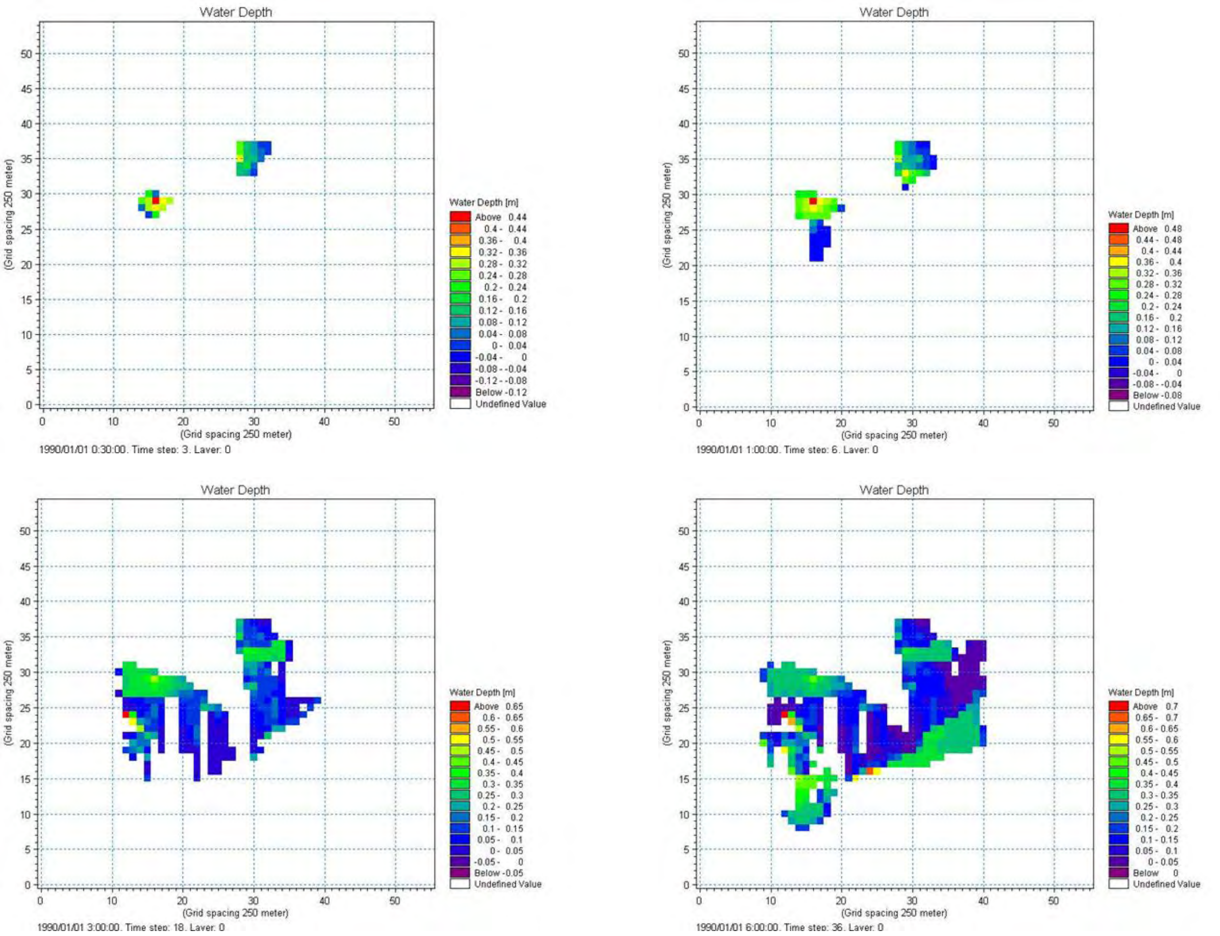
MIKE11 and MIKE21 have animation functions. Calculation results for hourly water level and inundation area with time by MIKE11、MIKE21 shall be presented by using these functions.

**<MIKE11: MIKEVIEW>**



**<MIKE21: >**




## D-5.6 Case Study

- MIKE11 : Badung River an Mati River
- MIKE21 : Inundation area in Denpasar City
- MIKEFLOOD : In Calculation

**DIRECTORATE GENERAL OF WATER RESOURCES,**
**MINISTRY OF PUBLIC WORKS**
**PUBLIC WORKS SERVICE, BALI PROVINCE**

# THE COMPREHESIVE STUDY
# ON
# WATER RESOURCES DEVELOPMENT
# AND MANAGEMENT IN BALI PROVINCE
# IN
# THE REPUBLIC OF INDONESIA

## FINAL REPORT
## SUPPORTING REPORT

## [E] WATER QUALITY AND ENVIRONMENT

**AUGUST 2006**

**JAPAN INTERNATIONAL COOPERATION AGENCY**

**YACHIYO ENGINEERING CO., LTD.**
**NIPPON KOEI CO., LTD.**

THE COMPREHENSIVE STUDY
ON WATER RESOURCES DEVELOPMENT AND MANAGEMENT
IN BALI PROVINCE IN THE REPUBLIC OF INDONESIA

SUPPORTING REPORT (E)
WATER QUALITY AND ENVIRONMENT

## TABLE OF CONTENTS

LIST OF TABLES



LIST OF FIGURES

# E-1 WATER QUALITY

## E-1.1 Water Quality Monitoring System

PPSA (Proyek Pengembangan dan Pengelolaan Sumber Air/Bali Water Resources Development and Management Project) of Dinas PU, Propinsi Bali (Public Works Service, Bali Province) has established a surface water quality monitoring program, covering all major inland rivers of Bali Province and the 4 major inland natural lakes of Batur, Beratan, Buyan and Tamblingan, as an integral component of hydraulic monitoring system, since 1999. The water quality monitoring program has been conducted annually covering both dry and rainy seasons at 60 monitoring stations and water quality data obtained is available in published book format up to the year 2003.

In 1999 there were in total of 54 monitoring stations (50 river 4 lake stations) that has been expanded to 60 stations (56 river and 4 lake stations) since 2000. The river systems having more than one (multiple) monitoring stations are Ayung River (6 monitoring stations), Badung River and Mati River (3 monitoring stations for each river) and Unda River (2 monitoring stations one each in Unda River and Telagawaja River both belonging to the same river system). Other than these 4 rivers all the remaining rivers and the 4 lakes are represented by one single monitoring station per river/lake.

The locations of the 60 water quality monitoring stations of PPSA along with the measured range of BOD levels by PPSA including the computed values of mean and median are given in Table-E.1 and the locations are also shown in Figure-E.1. The data available as per this existing inland surface water quality monitoring program of PPSA has been incorporated into the GIS system developed as per this master plan study. In the GIS these existing 60 water quality monitoring stations are designated in the numerical order from 1 to 60 as determined by the PPSA, which is also evident from Table-E.1 and Figure-E.1.

Moreover, BAPEDALDA of Bali Province has also been conducting a water quality monitoring program annually since 2002 targeting 22 major rivers passing through more than one regency, coastal sea waters in all major beaches around Bali and also some typical wastewaters from domestic, institutional and industrial sources. The river and other water quality data obtained up to the year 2004 is also available in annually published book format.

## E-1.2 Initial Water Quality Survey by JICA Study Team

Water quality survey by the JICA Study Team was conducted 2 times, each during the master plan and feasibility study stages. The water quality survey conducted during the master plan study stage is referred to as "Initial Water Quality Survey" and described under this section E.1.2 and the relevant evaluation of water quality in the subsequent Section E-1.3.

The water quality survey conducted during the feasibility study stage is referred to as "Supplemental Water Quality Survey" and described under the Section E-1.4.

### (1) Sampling and Analysis of Initial Water Quality Survey

The initial water quality survey conducted by the JICA Study Team was a comprehensive water quality measurement program encompassing all 3 major sources of inland water bodies, namely, surface water of rivers, lakes/dams and groundwater/springs covering the target area of this master plan, the entire Province of Bali including the Nusa Penida islands. In total 50 inland water sampling locations were selected with 25 in rivers, 5 in lakes/dams and 20 in groundwater/springs. The sampling was conducted during November and December 2004.

All of the 25 river sampling locations and 4 of the lake sampling locations (in total 29 locations) were selected from the existing PPSA inland water quality monitoring stations as described above. Accordingly the sampling locations that were specific to this JICA measurement program (initial water quality survey) are 1 dam location of Palasari dam in Jembrana Regency and all of the 20 groundwater/spring sampling locations spanning the whole Bali Island. It is noted that PPSA has no groundwater/spring water quality monitoring program. Moreover, in the GIS these 21 new sampling locations that are not a part of the existing monitoring program of PPSA are assigned numerical numbers starting from 100 to 120 in order to distinguish them from the PPSA GIS designation numbering system ranging from 1 to 60 assigned for the existing water quality monitoring stations.

The 50 water quality sampling locations of the Initial Water Quality Survey along with the measured values of TDS and BOD are given in Table-E.2 and the locations are also shown in Figure-E.2.

The parameters of water quality analysis are composed of both field measurement parameters at site and sampling and subsequent laboratory measurement parameters.

**(a) Field Measurement Parameters**

The following 5 parameters were determined at site in all 50 sampling locations. They are, water temperature, pH, EC (electric conductivity), turbidity and DO (dissolved oxygen).

**(b) Laboratory Measurement Parameters**

The parameters of laboratory analysis somewhat varied depending on the state of potential water pollution as well as the type of the inland water body selected for sampling and analysis of water quality. In particular, heavy metal elements and cyanide are incorporated as additional water quality parameters for laboratory measurements for rivers with potential industrial pollution focused on rivers in Denpasar City and Badung Regency and other regional urban/industrial areas of Bali Island as specific indicators of potential industrial pollution. Accordingly, the laboratory parameters of analysis are categorized into 2 groups of Group A and Group B.

The Group A parameters are general parameters and hence common to all 50 sampling locations, while Group B parameters are special ones targeting industrial pollution indicator parameters and were restricted to a total of 21 river water samples only (21 sampling locations in river). The Group A and Group B parameters are given below.

**Group A**: Chloride ($Cl^-$), TDS (Total dissolved solids), Nitrite ($NO_2$), Nitrate ($NO_3$), BOD/COD (Biochemical oxygen demand/Chemical oxygen demand), Total and Fecal coliform bacterial count (Coliforms and Fecal Coli), SS (Suspended solids), Total nitrogen (T-N) and Total phosphorus (T-P).

**Group B**: Heavy metals of 9 numbers (Cu, Pb, Zn, Hg, As, Cd, $Cr^{6+}$, Fe, Mn) and Cyanide ($CN^-$).

**(2) Results and Evaluation of Initial Water Quality Survey**

The results of water quality analysis of all 50 sampling locations are given in Appendix-1 separated according to the 3 types of inland water body of rivers (25 locations), lakes/dams (5 locations) and groundwater/springs (20 locations), while summarized results indicating the measured values of TDS and BOD is given in Table-E.2. At first, an evaluation of water quality focused only on this initial water quality survey results is made for illustrative purpose according to the above 3 categorized types of water bodies and dealt with below. Also this evaluation is made basically on a regency basis for rivers and groundwater/springs, while for lakes/dams on a cumulative basis considering their limited total number of only 5 locations. Allocation of a river to particular regency is made solely on the basis of the location of sampling. An overall water quality evaluation that is made based on the entire available data of PPSA, BAPEDALDA and this initial survey sampling result is summarized in the following Section E-1.3.

For the evaluation of water quality, the intended beneficial use based water quality standards for 4 classes of beneficial use that ranged from potable water use with treatment and others (Class-I use) to irrigation use (Class-IV use), promulgated by the Government of Indonesia (GOI) as the Annex of Regulation No. 82-2001 concerning the management of water quality and water pollution control, hereafter referred to as national water quality standards (NWQS), is basically used. This standards is dealt with in details in Section E-2.2 (also refer to Table-E.4).

## (a) River Water Quality Evaluation

### 1) Rivers of Denpasar City and Badung Regency

In total 4 rivers, namely, Ayung River (3 sampling locations), Badung River (3 sampling locations), Mati River (3 sampling locations) and Penet River (1 sampling location) was targeted for the initial water quality survey in these areas of Denpasar City and Badung Regency.

In overall on a comparative basis, Ayung River water quality is the best, with BOD level not exceeding 4 mg/l and DO level mostly exceeding 6mg/l, followed with Penet River and Mati and Badung rivers. In fact both Mati and Badung river BOD levels of about 20 mg/l in their mid and downstream reaches indicate very significant high pollution level for a river. Moreover, as per the above mentioned NWQS the water quality of both of these rivers are unsuited for any beneficial use, including the lowest Class-IV use as irrigation water for which the maximum permissible level of BOD is only 12 mg/l.

On the other hand both Ayung and Penet Rivers (with a BOD level not exceeding 6 mg/l) even in the strictest sense should be well suited for the Class III and Class IV beneficial uses of NWQS, namely, aquaculture, livestock farming and irrigation. In fact in an overall sense Ayung River is evaluated as suited for Class I beneficial uses of NWQS implying unrestricted beneficial use including as a source of potable water with treatment.

It is further noted that the deterioration in water quality of both Badung and Mati rivers is visually evident and should be attributed to the disposal of untreated wastewaters due to miscellaneous anthropogenic (human) activities from the highly developed and urbanized areas of Denpasar and Kuta.

### 2) Rivers of Gianyar Regency

In total 2 rivers, namely, Petanu River and Melangit River each with one sampling location was targeted for the initial water quality survey in this Gianyar Regency.

Both rivers are assessed of good water quality with BOD levels not exceeding 4 mg/l and DO levels more than 6 mg/l and hence suited for multiple beneficial uses. Even in the strictest sense both river waters meet the requirement for Class-II of NWQS, the requirement for all beneficial uses other than as a source for potable water supply. Still in an overall sense the water quality is assessed as suited for unrestricted multiple beneficial uses including as a source of potable water with treatment (Class I of NWQS).

### 3) Rivers of Klungkung and Karangasem Regencies

In total on the basis of names of rivers 2 rivers, namely, Jinnah River and Unda River, each with one sampling location, in Klungkung Regency and 3 rivers, namely, Telagawaja River, Buhu River and Nyuling River, each with one sampling location, in Karangasem Regency was targeted for the initial water quality survey. In fact Telagawaja River is the upstream reach of the Unda River and hence there were 2 sampling locations in the Unda river system spanning the regencies of Karangasem and Klungkung.

The water quality at upstream reach of the Unda River system (Telagawaja River) is assessed as pristine with extremely low BOD level of only around 1 mg/l and hence suited for unrestricted beneficial use. Even the downstream Unda River reach is assessed as good water quality with respect to its biological quality with a BOD level of around 3 mg/l. Still the factor that may limit its beneficial use is its physical quality of high dissolved solids content with a TDS level of around 1000 mg/l rather than anything else. A TDS level of 1000 mg/l is the maximum limitation as per the NWQS for all beneficial uses from Class I to Class III, other than for irrigation use of Class IV.

With respect to the other 3 rivers in Karagesem regency they are assessed as good water quality in an overall sense. But they are still considered as somewhat polluted for a rural river, especially

Buhu River. Rather high nitrate level exceeding 11 mg/l in Buhu River is a cause of concern that could also be attributed to irrigation/agricultural runoff. As per the NWQS water with nitrate level exceeding 10 mg/l is suited to only for Class III and Class IV beneficial uses of aquaculture, livestock farming and irrigation.

**4) Rivers of Tabanan Regency**

The 2 rivers, namely, Yeh Hoo River and Balian River each with one sampling location was targeted for the initial water quality survey in this Tabanan Regency.

The measured BOD level of about 16 mg/l in Yeh Hoo River indicates significant pollution level for a river. Hence, as per the NWQS, in a strict sense, the water quality of the river is unsuited for any beneficial use, including the lowest Class IV use as irrigation water for which the maximum permissible level of BOD is only 12 mg/l. Comparatively Balian River has a better quality with a BOD level of around 5 mg/l (high DO level of 7 mg/l) and hence in an overall sense should be suited at least for the Class III and Class IV uses of NWQS.

**5) Rivers of Jembrana Regency**

The 2 rivers, namely, Jogading River and Melaya River each with one sampling location was targeted for the initial water quality survey in this Regency.

The measured BOD level of about 20 mg/l in combination with a low DO level of 2 mg/l in Melaya River indicates very significant high pollution level for a rural river. Wastes of market origin located just upstream of the sampling location could be the cause of highly localized organic pollution. Still, as per the NWQS the water quality of the river at least at the sampling location (and also probably at its downstream) is unsuited for any beneficial use, including the lowest Class IV use as irrigation water. Comparatively Jogading River has a better quality, despite being located nearby the relatively urbanized area of Negara City, with a BOD level of around 9 mg/l (rather high DO level of 6 mg/l) and hence in an overall sense should be suited at least for the Class III and Class IV beneficial uses of NWQS, namely, aquaculture, livestock farming and irrigation.

**6) Rivers of Buleleng Regency**

In total 4 rivers, namely, Penarukan River, Buleleng River, Banyumala River and Sabah River (each river with 1 sampling location) was targeted by the initial water quality survey in this largest regency virtually spanning the entire northern region of the Bali Province.

Of these 4 rivers, Banyumala River is evaluated as most deteriorated with a measured BOD level of 11 mg/l, but still marginally meeting the requirement for Class IV beneficial use as irrigation water as per the NWQS. All the other 3 rivers are of similar water quality and not significantly deteriorated with a BOD level in the range of 4-6 mg/l (DO level in the range of 6-7 mg/l) and hence in an overall sense should be suited at least for the Class III and Class IV beneficial uses of NWQS.

**7) Toxic and Metallic Pollution**

Of all the 25 river locations sampled as described above, in 21 river locations except for those rivers passing through predominantly rural areas, cyanide (indicator of toxicity) and 9 metals was measured (Group B parameters as given under item (1) of above) as indicator of potential industrial pollution. The 4 rivers (also 4 river locations since each of these rivers had only one location of sampling) in which the Group B parameters were not measured are Melangit River (Gianyar Regency), Jinah River (Klungkung Regency), Nyuling River (Karangasem Regency) and Melaya River (Jembrana Regency).

In overall, toxic and metallic pollution level in all rivers except for the ones of Badung and Mati Rivers that passes through the highly developed areas of Denpasar and Kuta is assessed as not significant. As an example the cyanide level measured in these two rivers in all of their 6 sampling locations exceeded 0.01 mg/l, while the closest figure of 0.009 mg/l was measured in Penet River that also passes nearby the developed Badung area of Denpasar City. Other than for these 3 rivers of Badung Regency and Denpasar city the cyanide level measured in all other rivers did not exceed 0.006 mg/l. A cyanide level of more than 0.01 mg/l is considered as indication of significant toxicity.

In fact the biological pollution level of the two rivers of Badung and Mati are also the highest and hence evaluated as the worst polluted rivers in the whole province of Bali in a total and overall sense, which is also discernable form visual observation.

**(b) Lakes and Dam Water Quality Evaluation**

The 4 major natural lakes of central mountainous region of Bali targeted for the initial water quality survey are Batur, Beratan, Buyan and Tamblingan. These 4 natural lakes are also incorporated in the water quality monitoring system of PPSA. In addition Palasari Dam, the largest dam in Bali, located in the Jembrana Regency was also included in this survey. Accordingly, in total there was 5 lakes and dam sampling locations.

The water quality of the 3 natural lakes, namely, Beratan, Buyan and Tamblingan are assessed as pristine with extremely low BOD level of only around 1 mg/l and hence suited for unrestricted beneficial use (conform well into the Class I of NWQS). On the other hand even though the biological quality of Lake Batur is good with a BOD level of 3 mg/l, its physical quality of high dissolved solids contents with a TDS level exceeding 2000 mg/l, at least in a strict sense, renders it unsuited for any beneficial use including the Class IV use of irrigation as per the NWQS. A TDS level of 2000 mg/l is the maximum allowable limit even for the Class IV beneficial use of NWQS.

Concerning the Palasari Dam it is evaluated as significantly deteriorated with potential for eutrophication attributed to nutrient accumulation, which is also indicated by the significant levels of nitrogen (T-N) and phosphorus (T-P) measured in the dam. Still, the water quality of the dam is suited for Class IV beneficial use of irrigation as per the NWQS, the intended primary beneficial use of the dam water.

**(c) Groundwater and Spring Water Quality Evaluation**

In total 20 locations of groundwater (wells) and springs were selected for the initial water quality survey principally focusing the relatively dry zones of the Bali Province. Similar to that of rivers the quality is evaluated below based on the location of the well/spring in the respective regencies concerned.

**1) Wells and Springs of Denpasar City and Badung Regency**

In total 4 wells and 1 spring was targeted for the initial water quality survey in these areas of Denpasar City and Badung Regency. The 4 groundwater wells sampled are located in central Denpasar City, Sanur, Kuta and Nusa Dua (Benoa) areas while the spring is located in the central area of Badung Regency, named Jepun spring used as a source water supply by PDAM, Badung.

In overall the BOD levels measured in the entire 4 well are of similar order in the range of 4-5 mg/l and hence regarded as somewhat deteriorated for a groundwater. In fact in a strict sense as per the NWQS, this BOD level exceeded the limitation of 2 mg/l for Class I use as potable source and other unrestricted multipurpose use. Still the most significant factor that would limit the beneficial use of these entire wells as potable source is their high dissolved solids contents. The TDS level measured in 3 wells other than the Central Denpasar well exceeded 1000 mg/l, the maximum allowable limit of NWQS for most beneficial uses other than irrigation (Class IV). Even in the case of the Denpasar well the measured TDS level of 980 mg/l was only marginally less than 1000 mg/l. Accordingly, in overall, groundwater in Central Denpasar, Sanur, Kuta and Nusa Dua areas are regarded as unsuited as sources for potable water use principally due to their high dissolved solids contents.

Concerning the Jepun spring, its measured BOD level of 6 mg/l is rather high for spring water and hence should be regarded as somewhat deteriorated. As also noted above, in a strict sense as per the NWQS, this BOD level exceeded the limitation of 2 mg/l for Class I use as potable source and other unrestricted multipurpose use.

**2) Wells and Springs of Klungkung Regency**

All of the 2 wells and 3 springs sampling locations of this Klungkung Regency (in total 5 sampling locations) were in fact located in the Penida Islands of Nusa Lembongan and Nusa Penida. The 2 wells are located one each in Nusa Lembongan and Nusa Penida island coastal areas, while the entire 3 springs, namely, Sakti, Guyangan and Angkal are located in the Nusa Penida Island.

The water quality of both wells of Nusa Lembongan and Nusa Penida are evaluated as saline and totally unsuited for any beneficial use not only due to their extremely high dissolved solids contents with a TDS level of more than 8000 mg/l but also of the high chloride (salinity) contents of more than 3000 mg/l. Moreover, the high chloride contents in the wells should be attributed to seawater (salinity) intrusion into the groundwater in the sampled coastal areas of both islands. It is noted that the maximum allowable TDS level for any beneficial use including the Class IV use of irrigation as per the NWQS is only 2000 mg/l.

As per the 3 springs of Nusa Penida Island, the Angkal Spring is evaluated as saline having extremely high TDS level (about 11,000 mg/l) and chloride (salinity) level (more than 4000 mg/l), and hence unsuited for any beneficial use, a case similar to the 2 wells of above. While, the Sakti spring is evaluated as suited only for the Class IV beneficial use as irrigation water as per the NWQS due to its rather high TDS level of 1800 mg/l that exceeded the limitation of 1000 mg/l for source of potable water use. On the other hand Guyangan spring is evaluated as suited for multiple beneficial including as source of potable water use (Class I as per the NWQS) due to its relatively low TDS level (600 mg/l) and also its good biological quality with BOD level of 2 mg/l.

**3) Wells and Spring of Karangasem Regency**

In total 2 wells and 1 spring was targeted for the initial water quality survey in this Regency. The 2 groundwater wells sampled are registered wells of P2AT (Proyek Pengembangan Air Tanah/Groundwater Development Project) of Dinas PU, namely, Well No. NB12 located in Kubu and Well No. NB 49 located in Abang. The spring sampled, named Santi Spring, is located in Selat.

The water quality of Well NB.12 is evaluated as somewhat deteriorated not only due to its relatively rather high BOD level of 3 mg/l for groundwater but also of its high nitrate level of 9 mg/l that is near the limitation of 10mg/l for the Class I and Class II beneficial uses as per the NWQS, including as source of potable water use. Still in an overall sense the well water quality is evaluated as suited for Class I beneficial use of unrestricted multiple use including as potable water source. On the other hand the water quality of both the Well NB 49 and Santi Spring is evaluated as very good with extremely low BOD level of only 1 mg/l (and also low nitrate levels, especially in case of the Santi Spring that is in fact pristine) and hence suited for unrestricted multiple beneficial uses including as source of potable water use (Class I of NWQS).

**4) Wells of Jembrana Regency**

Entire 3 water quality sampling locations of this Regency consisted of only groundwater wells. The wells are located in Melaya (a hotel well in Gilimanuk), Negara (Well No. T35 of P2AT) and Pekutatan (Well No. T31 of P2AT).

In overall, water quality of all 3 wells is evaluated as very good with extremely low BOD level of only about 1 mg/l. Still high nitrate level just exceeding 10 mg/l was measured in the well in Gilimanuk. Moreover TDS level measured in this well was also rather high of about 900 mg/l. Accordingly, in an overall sense, groundwater in Gilimanuk area is evaluated as only marginally suited for unrestricted beneficial uses including as source of potable water use as per the Class I requirement of NWQS. On the other hand the other two groundwater wells (T31 and T35) are evaluated as fully suited for unrestricted multiple beneficial uses including as source of potable water use.

#### 5) Wells and Spring of Buleleng Regency

In total 3 wells and 1 spring was targeted for the initial water quality survey in this largest and mostly arid northern Regency of Bali Province. All 3 groundwater wells sampled are registered wells of P2AT of Dinas PU, namely, Well No. NB 47 located in Pejarakan (Gerokgak), Well No. NB 53 located in Patas (Gerokgak) and Well No. NB 63 located in Tukad Mungga (Buleleng). The spring sampled, named Saneh Spring, is located in Kubutambahan (Buleleng).

The water quality of 2 wells, Well NB.53 and Well NB 63 is evaluated as somewhat deteriorated due to their relatively rather high BOD level of 3 mg/l for groundwater. Moreover, the TDS level of around 800 mg/l is also rather high and near to the limit of 1000 mg/l for most beneficial uses of Class I to Class III of NWQS. On the other hand the water quality of Well NB 47 is evaluated as good with a BOD level of 2 mg/l and a TDS level around 500 mg/l. Still in an overall sense all 3 wells are evaluated as suited for unrestricted multiple use including as potable water source (Class I of NWQS).

On the other hand the water quality of Saneh Spring is evaluated as very good and in fact should be regarded as pristine with extremely low BOD level of only 1 mg/l and also TDS level around 500 mg/l and hence suited for unrestricted multiple beneficial uses.

### E-1.3 Overall Evaluation of Initial Water Quality Survey

An overall summary on evaluation of water quality that was made based on all available data of PPSA and BAPEDALDA as well as the results of the initial water quality survey by the JICA Study Team and also that of the relevant field observation is given below.

#### (1) Rivers

Based on all available data and also the recent measurement results of this survey as well as site inspection, the water quality in rural and upstream reaches of most rivers is regarded as good. As a typical example of very good, in fact regarded as pristine, river water quality of the Telagawaja River, which is the upstream rural river reach of Unda River is cited. On the other hand the Badung and Mati Rivers passing through the highly developed Denpasar and Kuta area in South Bali is evaluated as the worst polluted rivers in the whole province, which is also visually discernable. BOD levels even exceeding 70 mg/l were measured in these two rivers under dry weather flow condition. Moreover, water pollution level in these two rivers with respect to toxicity is also regarded as very significant. Untreated disposal of wastes arising from various human activities of domestic, commercial, industrial and other origin is the cause of this severe water quality deterioration.
Other regional rivers of significant water quality deterioration are identified to be located in the most downstream-developed river reaches of relatively arid regions like Negara and Singaraja and their surroundings. This water quality deterioration is regarded as confined to the dry season, though the dry season itself is rather long, principally due to the lack of river water flow in combination with untreated waste disposal consequent to various human activities.

Such arid rivers of significant water quality deterioration located in Jembrana Regency and also around Negara city are Jogading River passing through Negara city and the downstream reaches of Biluk Poh, Yeh Embang, Medewi and Pengiyangan rivers. Similarly, such rivers of Buleleng regency and located around Singaraja city are the downstream reaches of Sabah, Medaum, Banyumala and Daya Sawan rivers.

#### (2) Lakes and Dam

The water quality of all 5 major lakes and dam of Bali Island was investigated. Among them the 3 scenic lakes in the central mountainous region, namely, Beratan, Buyan and Tamblingan are regarded as pristine and have the best water quality for a lake. Also the quality of Batur Lake is good though its natural dissolved solid content is rather high. On the other hand Palasari dam has potential for eutrophication and hence regarded as rather deteriorated.

### (3) Groundwater and Springs

In overall, the quality of groundwater of South Bali area in the Central Denpasar and further south at Kuta and Nusa Dua is regarded as not suited as potable water sources since their dissolved solids content is high, in addition to the high salinity due to seawater intrusion in case of Kuta and Nusa Dua areas located adjacent to the coast. Moreover the coastal groundwater in Penida Islands of Nusa Penida and Nusa Lembongan is also saline due to seawater intrusion. The groundwater in the other mainland area of Bali Island is regarded as good and suited for unrestricted beneficial use including as source of potable water use.

Concerning the water quality of springs, those in mainland Bali Island are regarded as good and suited for unrestricted beneficial use. On the other hand in Nusa Penida Island it is identified that there is at least one freshwater spring with good water quality named Guyangan Spring, though there may exist additional springs of good water quality. Still it is known that there are also springs either with high dissolved solids content (Sakti Spring) or saline (Angkal Spring) that is basically not suited as a potable source.

## Table-E.1 Measured BOD level in Dinas P.U Monitoring Stations (1999-2003)

| No. | Name of River | Location | BOD(mg/l) | | | |
|---|---|---|---|---|---|---|
| | | | Max | Min | Med | Mean |
| 1 | Tk. Ayung 1 | Belok Sidan Bridge, Badung Regency | 4.2 | 0.5 | 2.4 | 2.6 |
| 2 | Tk. Ayung 2 | Rafting , Buangga Village, Badung Regency | 11.3 | 2.1 | 6.7 | 4.6 |
| 3 | Tk. Ayung 3 | Kedewatan Weir, Gianyar Regency | 17.4 | 2.0 | 9.7 | 7.0 |
| 4 | Tk. Ayung 4 | Mambal Weir, Badung Regency | 6.7 | 1.8 | 4.3 | 4.4 |
| 5 | Tk. Ayung 5 | Peraupan Weir, Denpasar City | 20.6 | 2.2 | 11.4 | 8.6 |
| 6 | Tk. Ayung 6 | Padanggalak Bridge, Denpasar City. | 17.3 | 2.2 | 9.8 | 8.2 |
| 7 | Tk. Badung 1 | Merta Gangga Weir, Denpasar City. | 50.0 | 4.2 | 27.1 | 15.2 |
| 8 | Tk. Badung 2 | Teuku Umar Bridge, Denpasar City | 65.7 | 6.3 | 36.0 | 17.9 |
| 9 | Tk. Badung 3 | Estuary Dam Bridge, Denpasar City | 135.4 | 6.1 | 70.7 | 32.1 |
| 10 | Tk. Mati 1 | Gt. Subroto Brt Bridge, Denpasar City | 22.7 | 2.2 | 12.5 | 10.1 |
| 11 | Tk. Mati 2 | Buana Kubu Bridge, Denpasar City | 33.2 | 6.2 | 19.7 | 15.0 |
| 12 | Tk. Mati 3 | Br. Plaza Kuta Bridge, Badung Regency | 74.0 | 8.2 | 41.1 | 23.8 |
| 13 | Tk. Yeh Buah | Penyaringan Bridge, Jembrana Regency | 37.5 | 1.1 | 19.3 | 11.5 |
| 14 | Tk. Biluk Poh | Tibu Tanggang Bridge, Jembrana Regency | 40.1 | 1.0 | 20.6 | 10.3 |
| 15 | Tk. Pergung | Rangdu Bridge, Jembrana Regency | 21.8 | 1.9 | 11.9 | 11.2 |
| 16 | Tk. Yeh Embang | Yeh Embang Bridge, Jembrana Regency | 48.2 | 4.3 | 26.2 | 22.7 |
| 17 | Tk. Yeh Satang | Tk. Medewi Bridge, Jembrana Regency | 23.5 | 2.4 | 13.0 | 9.1 |
| 18 | Tk. Yeh Sumbul | Yeh Sumbul Bridge, Jembrana Regency | 14.7 | 1.0 | 7.9 | 7.3 |
| 19 | Tk. Medewi | AWLR. Medewi, Jembrana Regency | 41.8 | 1.0 | 21.4 | 9.8 |
| 20 | Tk. Sangiang Gede | AWLR. Sangiang Gede, Jembrana Regency | 7.9 | 2.5 | 5.2 | 5.0 |
| 21 | Tk. Melaya | Melaya Bridge, Jembrana Regency | 22.4 | 2.3 | 12.3 | 9.6 |
| 22 | Tk. Daya Timur | Bale Agung Bridge, Jembrana Regency | 20.4 | 1.2 | 10.8 | 10.9 |
| 23 | Tk. Jogading | AWLR. Jogading, Jembrana Regency | 55.5 | 2.6 | 29.0 | 13.8 |
| 24 | T. Pengiyangan | Pengiyangan Bridge, Jembrana Regency | 47.8 | 1.7 | 24.8 | 16.6 |
| 25 | Tk. Pulukan | Bridge Pulukan, Jembrana Regency | 22.0 | 1.0 | 11.5 | 5.7 |
| 26 | Tk. Oos | AWLR. Silakarang, Gianyar Regency | 16.4 | 2.7 | 9.5 | 8.1 |
| 27 | Tk. Petanu | Blahbatuh Bridge, Gianyar Regency | 4.2 | 1.9 | 3.1 | 3.1 |
| 28 | Tk. Pakerisan | Lebah Bridge, Gianyar Regency | 9.3 | 0.7 | 5.0 | 3.8 |
| 29 | Tk. Sansang | Peteluan Bridge, Gianyar Regency | 25.5 | 2.9 | 14.2 | 12.4 |
| 30 | Tk. Melangit | Pagesangan Bridge, Gianyar Regency | 28.6 | 3.2 | 15.9 | 13.1 |
| 31 | Tk. Unda | AWLR. Klungkung, Klungkung Regency | 12.5 | 0.6 | 6.5 | 4.4 |
| 32 | Tk. Bubuh | Banjar Rangkan Bridge, Klungkung Regency | 26.2 | 1.4 | 13.8 | 7.9 |
| 33 | Tk. Jinah | Tak Mung Bridge, Klungkung Regency | 7.7 | 0.2 | 3.9 | 3.4 |
| 34 | Tk. Telaga Waja | Rendang Bridge, Karangasem Regency | 8.1 | 0.6 | 4.4 | 2.8 |
| 35 | Tk. Buhu | Ds. Sibetan Bridge, Karangasem Regency | 6.9 | 1.0 | 3.9 | 4.0 |
| 36 | Tk. Jangga | Ds. Janggapati Bridge, Karangasem Regency | 6.3 | 0.2 | 3.2 | 2.7 |
| 37 | Tk. Nyuling | Ds. Tumbu, Karangasem Regency | 7.7 | 0.4 | 4.0 | 3.2 |
| 38 | Tk. Sabah | AWLR. Seririt, Buleleng Regency | 37.5 | 4.0 | 20.7 | 14.8 |
| 39 | Tk. Medaum | Banjar Bridge, Buleleng Regency | 23.1 | 12.2 | 17.6 | 16.8 |
| 40 | Tk. Buleleng | AWLR. Bakung, Buleleng Regency | 14.5 | 3.2 | 8.8 | 8.3 |
| 41 | Tk. Penarukan | AWLR. Penarukan, Buleleng Regency | 24.6 | 2.7 | 13.7 | 11.1 |
| 42 | Tk. Daya Sawan | Sawan Bridge, Buleleng Regency | 45.5 | 2.9 | 24.2 | 14.8 |
| 43 | Tk. Banyumala | Banyumala Bridge, Buleleng Regency | 26.2 | 4.1 | 15.2 | 10.9 |
| 44 | Tk. Grokgak | Weir Grokgak, Buleleng Regency | 27.5 | 4.2 | 15.8 | 11.6 |
| 45 | Tk. Yeh Abe | Pesiapan Bridge, Tabanan Regency | 8.7 | 1.5 | 5.1 | 5.1 |
| 46 | Tk. Sungi | Abiantuwung Bridge, Tabanan Regency | 4.9 | 1.4 | 3.1 | 3.1 |
| 47 | Tk. Yeh Otan | Ds. Bajra Bridge, Tabanan Regency | 7.3 | 3.3 | 5.3 | 5.8 |
| 48 | Tk. Yeh Hoo | Dusun Timpag Bridge, Tabanan Regency | 7.8 | 2.4 | 5.1 | 4.9 |
| 49 | Tk. Balian | Ds. L. Linggah Bridge, Tabanan Regency | 9.1 | 2.4 | 5.8 | 6.8 |
| 50 | Tk. Yeh Leh | Yeh Leh Bridge, Jembrana Regency | 6.7 | 2.0 | 4.4 | 4.5 |
| 51 | Batur Lake | Batur Lake, Bangli Regency | 16.8 | 2.8 | 9.8 | 6.4 |
| 52 | Buyan Lake | Buyan Lake, Buleleng Regency | 10.6 | 1.4 | 6.0 | 5.3 |
| 53 | Beratan Lake | Beratan Lake, Tabanan Regency | 11.2 | 1.1 | 6.2 | 5.8 |
| 54 | Tamblingan Lake | Tamblingan Lake, Buleleng Regency | 11.5 | 1.1 | 6.3 | 5.0 |
| 55 | Tk. Sebual | AWLR. Sebual, Jembrana Regency | 22.7 | 1.7 | 12.2 | 8.7 |
| 56 | Tk. Yeh Matan | Brembeng Bridge, Tabanan Regency | 6.7 | 2.5 | 4.6 | 4.6 |
| 57 | Tk. Yeh Empas | Celagi Bridge, Tabanan Regency | 6.0 | 1.0 | 3.5 | 4.4 |
| 58 | Tk. Panahan | Grokgak Bridge, Tabanan Regency | 8.4 | 7.2 | 7.8 | 7.8 |
| 59 | Tk. Penet | Kapal Bridge, Badung Regency | 6.7 | 2.8 | 4.8 | 4.8 |
| 60 | Tk. Buus | Penarukan Bridge, Buleleng Regency | 16.1 | 8.8 | 12.4 | 12.4 |

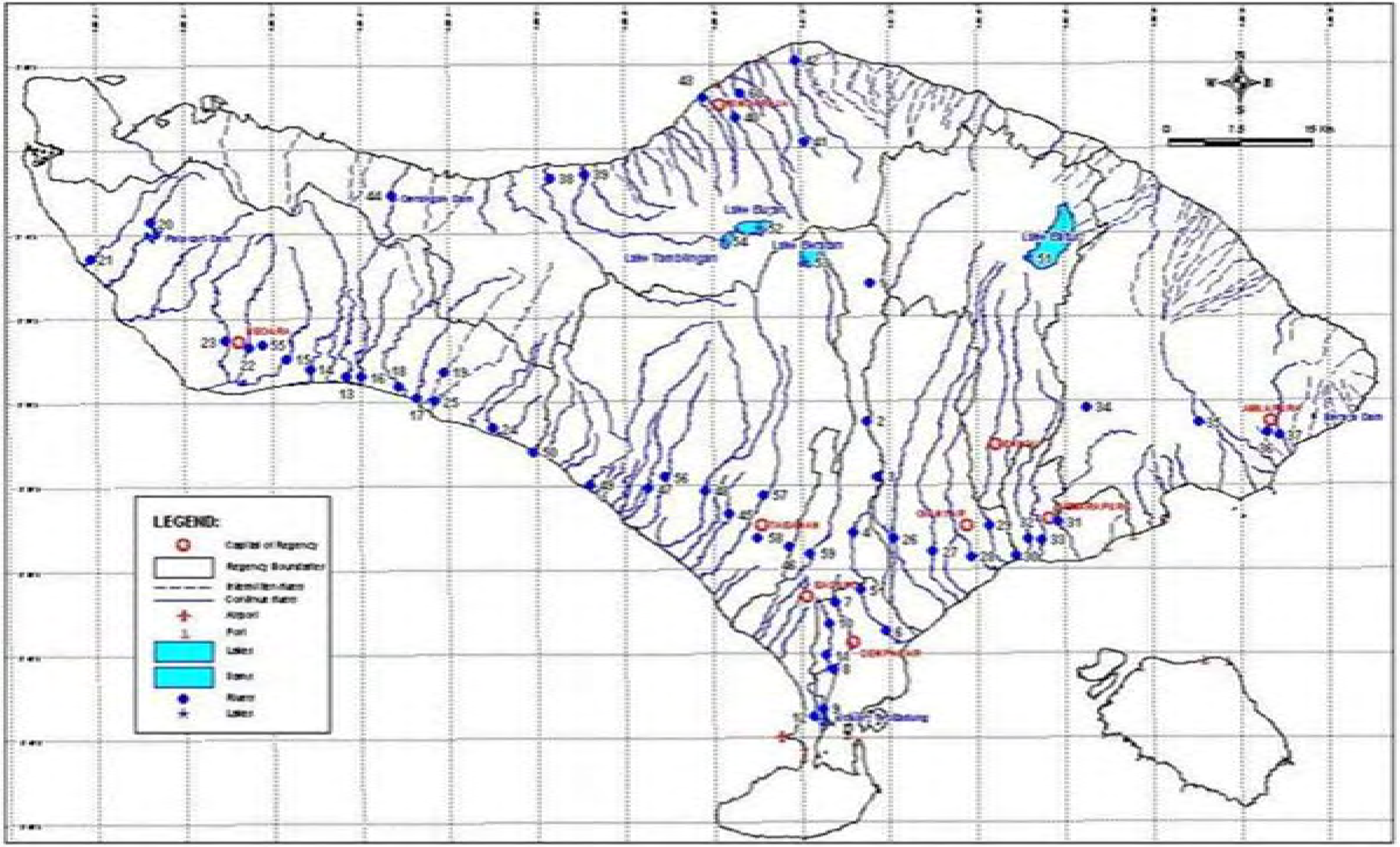



**Figure-E.1 Location of Dinas PU Monitoring Stations ( Rivers and Lakes )**

**Table-E.2 Initial Water Quality Sampling Results (TDS and BOD values)**

| No. | GIS. No | Name | Location | TDS (mg/l) | BOD (mg/l) |
|---|---|---|---|---|---|
| 1 | 1 | Tk. Ayung 1 | Belok Sidan Bridge, Badung Regency | 440 | 3.7 |
| 2 | 5 | Tk. Ayung 5 | Peraupan Weir, Denpasar City | 140 | 3.6 |
| 3 | 6 | Tk. Ayung 6 | Padanggalak Bridge, Denpasar City | 160 | 3.6 |
| 4 | 7 | Tk. Badung 1 | Merta Gangga Weir, Denpasar City | 280 | 9.9 |
| 5 | 8 | Tk. Badung 2 | Teuku Umar Bridge, Denpasar City | 240 | 20.7 |
| 6 | 9 | Tk. Badung 3 | Estuary Dam Bridge, Denpasar City | 380 | 17.8 |
| 7 | 10 | Tk. Mati 1 | Gt. Subroto Brt Bridge, Denpasar City | 280 | 3.7 |
| 8 | 11 | Tk. Mati 2 | Buana Kubu Bridge, Denpasar City | 280 | 19.1 |
| 9 | 12 | Tk. Mati 3 | Br. Plaza Kuta Bridge, Badung Regency | 300 | 17.7 |
| 10 | 21 | Tk. Melaya | Melaya Bridge, Jembrana Regency | 560 | 19.8 |
| 11 | 23 | Tk. Jogading | AWLR. Jogading, Jembrana Regency | 680 | 9.0 |
| 12 | 27 | Tk. Petanu | Blahbatuh Bridge, Gianyar Regency | 760 | 3.5 |
| 13 | 30 | Tk. Melangit | Pagesangan Bridge, Gianyar Regency | 480 | 2.2 |
| 14 | 31 | Tk. Unda | AWLR. Klungkung, Klungkung Regency | 960 | 3.2 |
| 15 | 33 | Tk. Jinah | Tak Mung Bridge, Klungkung Regency | 320 | 2.7 |
| 16 | 34 | Tk. Telaga Waja | Rendang Bridge, Karangasem Regency | 480 | 1.1 |
| 17 | 35 | Tk. Buhu | Ds. Sibetan Bridge, Karangasem Regency | 160 | 2.9 |
| 18 | 37 | Tk. Nyuling | Ds. Tumbu Bridge, Karangasem Regency | 380 | 3.3 |
| 19 | 38 | Tk. Sabah | AWLR. Seririt, Buleleng Regency | 840 | 5.3 |
| 20 | 40 | Tk. Buleleng | AWLR. Bakung, Buleleng Regency | 260 | 6.3 |
| 21 | 41 | Tk. Penarukan | AWLR. Penarukan, Buleleng Regency | 160 | 4.3 |
| 22 | 43 | Tk. Banyumala | Banyumala Bridge, Buleleng Regency | 720 | 10.9 |
| 23 | 48 | Tk. Yeh Hoo | Dusun Timpag Bridge, Tabanan Regency | 320 | 15.8 |
| 24 | 49 | Tk. Balian | Ds. L. Linggah Bridge, Tabanan Regency | 280 | 5.1 |
| 25 | 51 | Batur Lake | Batur Lake, Bangli Regency | 2,120 | 3.3 |
| 26 | 52 | Buyan Lake | Buyan Lake, Buleleng Regency | 130 | 1.1 |
| 27 | 53 | Beratan Lake | Beratan Lake, Tabanan Regency | 160 | 1.1 |
| 28 | 54 | Tamblingan lake | Tamblingan Lake, Buleleng Regency | 120 | 1.3 |
| 29 | 59 | Tk. Penet | Kapal Bridge, Badung Regency | 140 | 5.6 |
| 30 | 100 | Palasari Dam | Ekasari Village, Jembrana Regency | 540 | 7.8 |
| 31 | 101 | Sari Hotel Well | Gilimanuk Village, Jembrana Regency | 884 | 0.9 |
| 32 | 102 | Well T.35 | Tegal Badeng Village, Jembrana Regency | 478 | 1.3 |
| 33 | 103 | Well T.31 | Gumbrih Village, Jembrana Regency | 786 | 1.3 |
| 34 | 104 | Well Inna Bali Hotel | Veteran Street , Denpasar City | 980 | 5.2 |
| 35 | 105 | Well Diwangkara Hotel | Hangtuah Street, Denpasar City | 1,620 | 4.5 |
| 36 | 106 | Well Kuta Timur Resort | Ngurah Rai By Pass, Denpasar City | 2,160 | 4.1 |
| 37 | 107 | Well Puri Benoa Hotel | Pratama Street, Badung Regency | 1,400 | 4.0 |
| 38 | 108 | Jepun Spring | Banjar Pergan Tabanan Regency | 420 | 6.2 |
| 39 | 109 | Well NB.47 | Pejarakan Village, Buleleng Regency | 484 | 1.7 |
| 40 | 110 | Well NB.53 | Patas Village, Buleleng Regency | 840 | 3.2 |
| 41 | 111 | Well NB.63 | Tukad Mungga Village, Buleleng Regency | 740 | 3.5 |
| 42 | 112 | Mata Air Sanih | Bukti Village, Buleleng Regency | 480 | 1.0 |
| 43 | 113 | Well NB.12 | Tianyar Village, Karangasem Regency | 460 | 3.5 |
| 44 | 114 | Well NB.49 | Purwakerthi Village, Karangasem Regency | 400 | 1.0 |
| 45 | 115 | Santi Spring | Selat Village, Karangasem Regency | 400 | 0.9 |
| 46 | 116 | Sakti Spring | Sakti Village, Klungkung Regency | 1,800 | 2.3 |
| 47 | 117 | Guyangan Spring | Batu Kandik Village, Klungkung Regency | 600 | 2.1 |
| 48 | 118 | Angkal Spring | Suana Village, Klungkung Regency | 10,940 | 2.6 |
| 49 | 119 | Well Waka Nusa Resort | Nusa Lembongan, Klungkung Regency | 16,840 | 4.5 |
| 50 | 120 | Well Tenang Motel | Toya Pakeh Nusa Penida, Klungkung Regency | 8,620 | 5.1 |

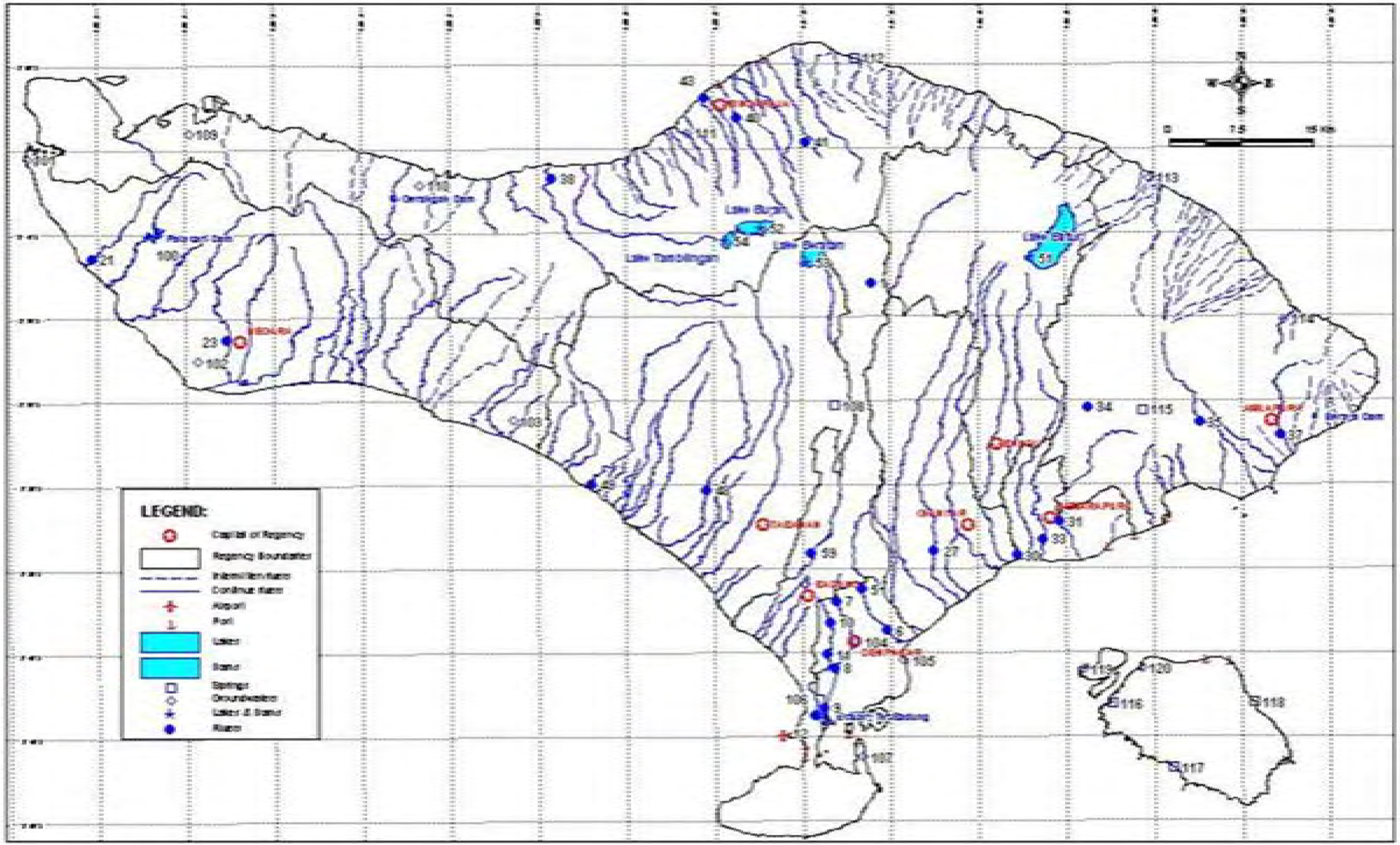



**Figure-E.2 Initial Water Quality Sampling Locations**

### E-1.4 Supplemental Water Quality Survey by JICA Study Team

The supplemental water quality survey was conducted during the feasibility study stage specifically targeting the rivers of priority (feasibility study) projects of Multipurpose Ayung Dam Development Project, the 3 potable water supply development projects for Denpasar Metropolitan area and its surroundings, namely, West Region Project, Central Region Project and East Region Project and the flood control projects in the 2 rivers of Badung and Mati, located also in the Denpasar area and its vicinity. Moreover, introduction of dilution water from Ayung River to Badung River as environmental flow during dry weather flow condition using available excess water released from the Ayung Dam is also considered. Such dilution water to Badung River could be introduced using existing irrigation canal that connects Ayung River to Badung River via Oongan Weir of Ayung River.

#### (1) Sampling and Analysis of Supplemental Water Quality Survey

The supplemental water quality survey conducted by the JICA Study Team targeted in total 14 locations, all in rivers. The rivers of sampling are Ayung River including its upstream tributary Siap River (7 locations), Penet River (2 locations), Petanu River (2 locations) and one location each in Oos River, Badung River and Mati River. The sampling was conducted during October 2005. The sampling locations numbered from 1 to 14 are shown in Figure-E.3 and the measured values for some significant parameters are given in Table-E.3.

It is noted that location numbers 3,4 and 5 of Ayung River correspond to the proposed location of Ayung Dam, location numbers 6 and 7 of Ayung River correspond to the raw water intake area of Central Region Project and location number 8 of Ayung River is the Oongan Weir mentioned above intended at providing dilution water as environmental flow to Badung River. Other sampling locations significant to raw water intake for portable water supply are location numbers 10 and 11 of Penet River that correspond to West Region Project and location numbers 12 and 13 of Petanu River that correspond to East Region Project.

The parameters of water quality analysis are composed of both field measurement parameters at site and sampling and subsequent laboratory measurement parameters. The selected parameters that are common to all 14 river sampling locations included all items as specified by the NWQS of Indonesia as well in addition to other parameters (ref. Table-E.4).

#### (a) Field Measurement Parameters

The following 5 parameters were determined at site. They are, water temperature, pH, EC (electric conductivity), turbidity and DO (dissolved oxygen). In addition river discharge during sampling was also measured.

#### (b) Laboratory Measurement Parameters

The parameters of laboratory analysis in total composed of 26 parameters as given below.

Chloride ($Cl^-$), TDS (Total dissolved solids), Ammonia ($NH_3$), Nitrite ($NO_2$), Nitrate ($NO_3$), BOD, COD, Total and Fecal coliform bacterial count (Coliforms and Fecal Coli), SS (Suspended solids), Total nitrogen (T-N), Total phosphorus (T-P), Heavy metals of 13 numbers (Cu, Pb, Zn, Hg, As, Cd, $Cr^{6+}$, Co, Ba, B, Se, Fe, Mn) and Cyanide ($CN^-$).

#### (2) Results and Evaluation of Supplemental Water Quality Survey

The results of water quality analysis of all 14 river sampling locations are given in Appendix-2, while summarized results indicating the measured values of TDS, DO and BOD is given in Table-E.3.

In overall, the water quality results for all 6 rivers (Badung River, Mati River, Ayung River including its upstream tributary of Siap River, Penet River, Petanu River and Oos River are in agreement with the results of initial water quality survey for rivers as well as available data on water quality as reported by PPSA and BAPEDALDA. Accordingly, the water quality evaluation illustrated in details in the forgone Section E-1.2 and further summarized in Section E-1.3 is valid for this supplemental sampling result on river water quality as well and hence not repeatedly analyzed here in details.

Still in overall gradual deterioration in the water quality of Ayung River as it descends from upstream to downstream is evident from corresponding gradual increase in BOD (COD) levels and decrease in DO levels (ref. Table-E.3). Still, in overall sense even at its most downstream PDAM raw water intake location of Waribang (location No.9 of Figure-E.3) the water quality of Ayung River is assessed as critically satisfactory as source of raw water for conventional potable water treatment. Moreover, similarly both the Penet and Petanu rivers, even at their downstream locations as planned for raw water intake of West Region Project (Penet River in location No. 11) and East Region Project (Petanu River in location No. 13), are assessed as suited as source of raw water for conventional potable water treatment. In fact the water quality of these two rivers are better than that of Ayung River at Waribang.

It is further noted that the water quality of Ayung River even its upstream reaches, immediate upstream of the planned Ayung Dam (location No. 3 and 4 of Figure-E.3) have significant levels of nutrients indicated by T-N (total nitrogen) of more than 3 mg/l and T-P (total phosphorus) of just more than 0.01 mg/l. In fact the T-P level measured exceeded 0.3 mg/l in all river-sampling locations downstream of the planned Ayung (Buangga) Dam (from location No. 5 through location No.9). Accordingly, it is postulated that the stored water of future Ayung Dam has some potential for eutrophication that may affect its suitability as raw water source for conventional potable water treatment. Still, since the dam is deep with water depth of more than 50m no significant eutrophication is anticipated, provided the land-use of the river drainage basin at upstream of the dam (area of about 218 $km^2$) remains protected with no significant future intensive agricultural and other developments that might contribute to increased nutrient inflow to the dam. In fact the protection of the dam drainage basin against any further development is important for both the protection of water quality of dam against eutrophiction and also to control sediment inflow to the dam that would eventually affect the life of dam.

Still, as the natural means to control the proliferation of phytoplankton in dam water, the cause of eventual eutrophication, introduction of plankton gracing fresh water fish species that are also economically valuable could be considered. Such introduced fish species will solely depend on naturally available plankton and other biomass in water as their feed and in principle no artificial feeding would be permitted. With regular harvesting of such matured fish (that may be sold in the market) the fresh water aquatic ecosystem of the dam could be maintained even pristine, similar to the central mountain natural lakes (Beratan, Buyan and Tamblingan), and free from eutrophication.

**Table-E.3 Supplemental Water Quality Sampling Results (TDS, DO and BOD values)**

| No. | Location | TDS (mg/l) | DO (mg/l) | BOD (mg/l) |
|---|---|---|---|---|
| 1 | Buagan Weir, Badung River | 320 | 1.1 | 22.6 |
| 2 | Plaza Kuta Bridge, Mati River | 1,300 | 1.2 | 15.9 |
| 3 | Finish Discovery Rafting, u/s Dam, Ayung River | 200 | 9.3 | 2.6 |
| 4 | Susut-Buagan Bridge, u/s Dam, Siap River (Ayung Tributary) | 190 | 6.9 | 2.9 |
| 5 | Start Ayung River Rafting, d/s Dam, Ayung River | 170 | 7.1 | 3.2 |
| 6 | Mambal Weir, Ayung River | 210 | 6.6 | 5.5 |
| 7 | Peraupan Weir (PDAM Intake), Ayung River | 180 | 6.2 | 5.1 |
| 8 | Oongan Weir, Ayung River | 180 | 5.6 | 5.5 |
| 9 | Waribang (PDAM Intake), Ayung River | 190 | 6.6 | 5.5 |
| 10 | Kapal Bridge, Penet River | 260 | 6.4 | 3.7 |
| 11 | Nyanyi (PDAM Intake), Penet River | 240 | 7.1 | 2.3 |
| 12 | Blahbatuh Bridge, Petanu River | 200 | 6.4 | 1.4 |
| 13 | Tohpati-Kusamba Bridge, Petanu River | 220 | 5.9 | 2.1 |
| 14 | Tohpati-Kusamba Bridge, Oos River | 300 | 6.1 | 2.4 |

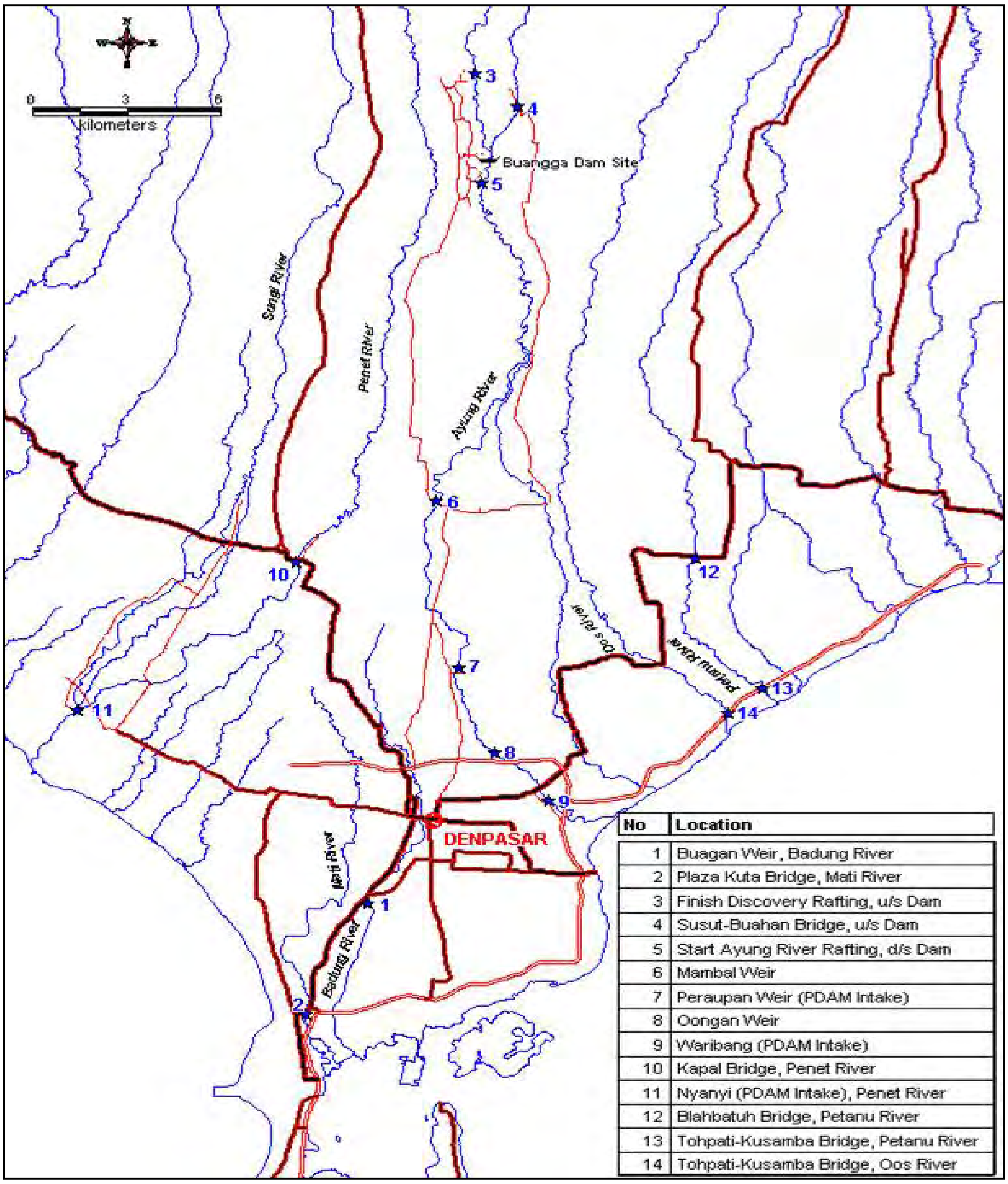



**Figure-E.3 Supplemental Water Quality Sampling Locations**

# E-2 ENVIRONMENTAL ASPECTS

## E-2.1 Natural Environment

### (1) General

The natural environment of Bali had been long modified since ancient times due to anthropogenic (human) activities, principally due to rice farming (paddy cultivation), which is understandable since it is a highly populated small fertile island. Lately, its development as a famous tourism destination in a sense exerts further pressure on the natural environmental resources of the Island. Nevertheless, since it is such natural environmental resources that sustain the tourism development and hence tourism development has also helped in increased awareness on the importance of protection and conservation of natural environment.

Bali is a small tropical Island (area of about 5633 km$^2$) located just about 8$^0$ south of the equator. The island is separated virtually into two major drainage basins of north and south by the central mountain range that crosses the island in the east-west direction. The northern region is relatively arid in comparison to the southern region. In particular the central and eastern part of the southern region receives much higher rainfall and hence agriculture, principally rice cultivation, is most well developed. The average annual rainfall is around 3000 mm, though it is subjected to seasonal and geographic variation with most rainfall being confined to the wet season from November to March.

The most significant scenic feature of the Island, in addition to the terraced rice fields, is the 4 natural lakes in the central mountainous region, namely Lake Batur, Lake Beratan, Lake Buyan and Lake Tamblingan and the mountains of Gunung Agung and Gunung Batur. In fact the steep topography around the central mountain range renders the area unsuited for agricultural development and hence this region virtually remains as forestation. Most of these highland forests are declared as protected areas and constitute as the principal water catchments for the 4 natural lakes and the numerous rivers of the island.

The significant coastal natural resources having much tourism importance as well include golden (white) sand beaches concentrated in southern coasts of Bali (Sanur, Kuta, Jimbaran and Nusa Dua), and coral reefs concentrated principally in southern coastal waters of Sanur and Nusa Dua as well as the small islands of Nusa Lembongan (and Nusa Ceningan) and also the eastern (Amed and Tulamben areas) and western (Menjangan Island) coastal waters of the mainland Island.

The other ecologically most significant coastal natural resource of the Island includes its mangrove forestation principally concentrated in the southeastern coast of the Island along the Benoa Bay. This mangrove forestation, though affected in the past and converted into fish and shrimp ponds, has been rehabilitated and also declared as a protected coastal forest area (Ngurah Rai Great Forest Park). The other coastal areas of significant mangrove vegetation include Nusa Lembongan Island and the western most coasts of Gilimanuk Bay and Menjangan Island.

**(2) Protected Areas**

Most of the highland central mountainous region of the island is declared as some form of nature reserve or natural tourism park and hence remains as protected area. Such terrestrial mountainous protected areas include, but not limited to, the following;

1. Batukaru Nature Preserve Area located around Batukaru mountain range
2. Natural Tourist Park of Lake Buyan-Tamblingan located around these lakes
3. Natural Tourist Park of Sangeh located in the tourism area of monkey forest
4. Natural Tourist Park of Penelokan located around Lake Batur

The other protected areas that are composed of lowland terrestrial area and/or coastal marine waters include, but not limited to, the following;

1. Bali Barat National Park (BBNP) or Taman Nasional Bali Barat located in the western region of Bali including the coastal marine areas around Gilimanuk Bay and Menjangan Island and hence incorporates coastal mangrove vegetation and coral reefs as well
2. Ngurah Rai Great Forest Park located around the Benoa Bay at southeast coast, which is the largest mangrove forest area in the Island

These protected and nature reserve areas of the whole Bali Island is shown in Figure-E.4 for illustrative purpose (Source: Department of Forestry, Bali Province). These protected areas serve also as important habitat for the rare and endangered fauna and flora of the island. Of all those protected areas in Bali, BBNP has the distinction as the only national park as also implied by its name.

**(3) Fauna and Flora**

Bali is a geologically young island. As such basically there is no native fauna and flora species specific to the island. In other words virtually everything exists here is basically migrated from somewhere around. Still the favorable tropical climate of the Island along with its wide variation in altitude and high fertility renders it habitable for a variety of fauna and flora. Nevertheless, since nearly the entire island other than the steep slope mountainous region has been cultivated over centuries, anthropogenic (human) effects on the environment and hence on the fauna and flora of the island is very significant. Existence of a variety of flowering plants all over Bali could be considered as the most significant consequence of anthropogenic effect on the flora species of the island. Human effects on fauna is evident from existence of a variety of domesticated animals and livestock (pigs, chicken, ducks, cows, dogs and others).

Consequent to the extensive cultivation induced anthropogenic effects on species of the island, traces of earlier plant life could be found only in the BBNP. Accordingly, conservation and management of this national park is very important. The park is managed by the Department of Forestry that has its park management office in Cekik. In fact BBNP serves as habitat for a number of endangered fauna and flora of the island, of which the most significant fauna is the bird species endemic to Bali, the Bali Starling (*Leucopsar rothschildi*), which is locally known as Jalak Putih/Jalak Bali. BBNP is reported to serve as habitat to a total of 10 species of endangered fauna and 14 species of endangered flora.

The coastal marine water around Bali is also home to a rich variety of marine fauna and flora including corals and mangroves as noted above and also fish, turtles, dolphins (mostly in the northern coastal waters off Singaraja), seaweeds and others. In fact the beauty of the corals and the rich marine life surrounding them is an important element of marine tourism (diving/snorkeling) in the island. Of the marine life of Bali the most significant marine fauna that is endangered and hence its capture as well as gathering of its eggs is legally banned (in fact banned throughout the Indonesian coast), is the two turtle species of green sea turtle and hawksbill turtle.

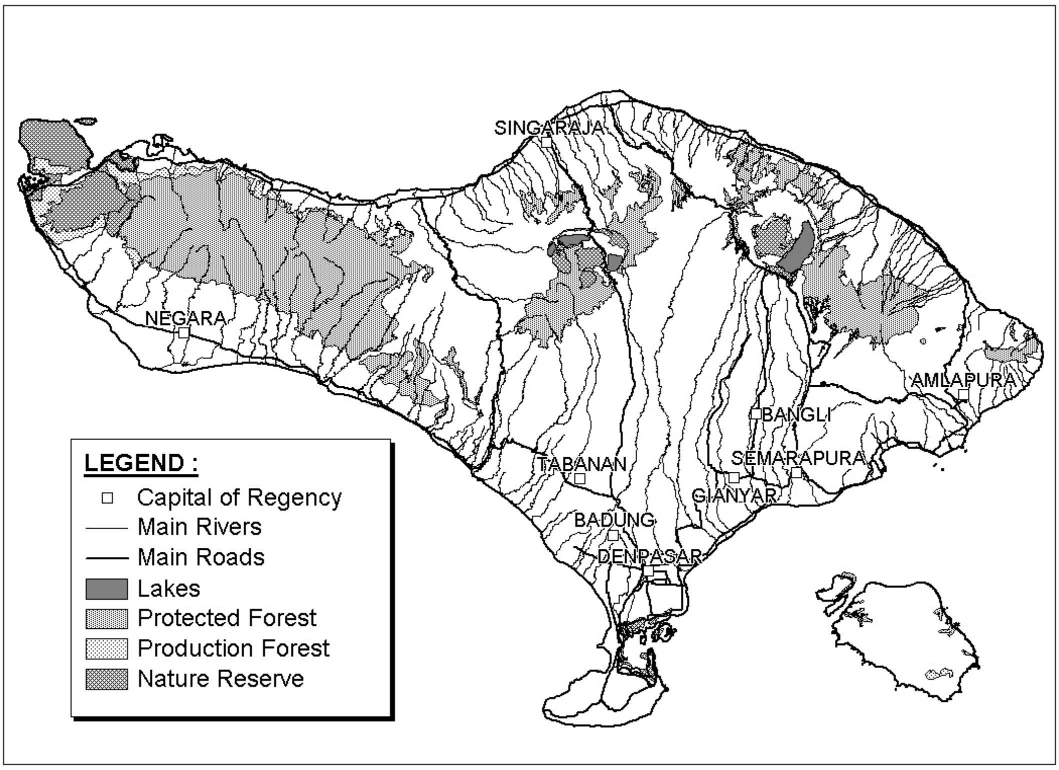



**Figure-E.4 Map of Protected Areas in Bali**

### E-2.2 Environmental Regulations and Standards

#### (1) Basic Environmental Laws and Regulations

The original basic law on environment was promulgated by the Government of Indonesia (GOI) in 1982 and known as Law No.4/1982. This law was updated in 1997 to become the new basic environmental law of the times (law concerning environmental management) as Law No.23/1997. This new basic environmental law (No. 23/1997) under Article 14 stipulates the formulation of environmental quality standards and under Article 15 stipulates the conduct of environmental impact analysis for projects with significant impacts.

Consequently Government Regulation No.27/1999 (PP27/1999) was published on Environmental Impact Assessment (EIA/AMDAL) and Government Regulation No.82/2001 (PP82/2001) was published on management of water quality and water pollution control as the most up to date regulations relevant to this master plan and feasibility study on water resources development and management. In fact the beneficial use based national water quality standards (NWQS) used for the evaluation of water quality in foregone Section E-1 is published as the APPENDIX of PP82/2001 (refer to Table-E.4). This is dealt with further under Environmental Standards of below.

**(2) EIA/AMDAL Regulations and Processes**

The EIA process in Indonesia known as AMDAL (Analysis Mengenai Dampak Lingkungan) is characterized by its absence of IEE (Initial Environmental Examination) in a formal/legal sense. Still the formulation of Terms of Reference (TOR) of EIA (known as KA ANDAL) and the screening and scoping process involved in its formulation could still be regarded as IEE.

The AMDAL process was originally included in law through Government Regulation No. 29 of 1986 (PP29/1986), promulgated under Law No. 4/1982 as noted above. Accordingly AMDAL process has already been well established in Indonesia since 1986. It is noted that Law No. 4/1982 has been replaced with Law No. 23/1997 and PP29/1986 with PP27/1999 as also referred above.

Environmental Impact Management Agency of the respective province or regency concerned (Badan Pengendalian Dampak Lingkungan Daerah; BAPEDALDA) is the responsible agency for the guidance and management of AMDAL study. Since the promulgation of Law No.22/1999 on Regional Autonomy, responsibility of the AMDAL process has been delegated to the respective BAPEDALDA of the concerned province if the project plan involves or potentially affects more than one regency of the province concerned. On the other hand if the project plan completely falls within one regency then it is under the responsibility of BAPEDALDA of the concerned regency only.

Other significant regulations (decrees) and guidelines that have to be followed in the conduct of AMDAL (EIA) study are given below.

1. Decree of the Minister of State for Environment No.2/2000 on Guidance on the Evaluation of the EIA (AMDAL) Document.
2. Decree of the Decision of the Minister of State for Environment No.40/2000 on Guidance on the Working Procedure of the EIA Commission.
3. Decree of the Minister of State for Environment No.41/2000 on Guidance on the Establishment of Commission for the EIA Evaluation in Regency/City.
4. Decree of the Minister of State for Environment No.42/2000 on Guidance on the Formation of Evaluation Team and Technical Team Members for the EIA.
5. Decree of the Minister of State for Environment No.17/2001 on Types of Business and /or Activities that are Required to be Provided with EIA.
6. Decision of the Environmental Impact Management Agency No.9/2000 on Guidance on Preparation of the EIA Document.
7. Decision of the Environmental Impact Management Agency No.8/2000 on Guidance on Public Participation and Information Disclosure of the EIA Process.

It is noted that for the conduct of EIA study Indonesia has developed a licensing system as certification for the experts who are basically eligible as team members to carry out an EIA study. The certification system is for 3 categories of expertise known as AMDAL-A, AMDAL-B and AMDAL-C.

AMDAL-A certification is the basic qualification allowing one to participate as a team member of EIA (AMDAL) study team, while AMDAL-B is for professional who could carry out environmental impact analysis and is the next second grade of the certification system. Only an expert possessing at least AMDAL-B certification could be the Team Leader of an EIA (AMDAL) Study Team and this requirement is specified in the Decision No9/2000 of Item 6 of above. AMDAL-C is the highest grade of the certification system and an expert possessing the certification is eligible to carry out all aspects of EIA study including making recommendations on environmental improvement, management and monitoring measures and hence naturally eligible to be the Team Leader of an EIA Study Team. Nevertheless, it is not mandatory that all members of an EIA Study Team should possess an AMDAL certification to become a study team member. An expert with specialized qualification is eligible for participation as EIA study team member though not eligible to be the Team Leader. AMDAL Study is conducted by a technical team of experts employed by the proponent of the project plan with its Team Leader having AMDAL-B certification as the minimum requirement.

Moreover, the Decree No17/2001 (Item 5 of above) specifies project activities subjected to mandatory EIA (AMDAL) Study principally based on the scale of a project. This Decree is basically reviewed at least once in 5 years and updated to account for the change in times and currently this remains as the latest valid Decree. This decree categorizes a project/business activity into 14 sectors ranging from Sector A to Sector N with Sector A being Defense and Security Sector and Sector N being Genetic Engineering Sector.

The sector having much relevance to the projects of this master plan is the Sector I on Regional Infrastructure that covers most project activities undertaken by the PU. For example in this Sector I AMDAL process requirement for the construction of a dam (reservoir) is specified under Item 1. Accordingly AMDAL process is mandated for a dam either of height more than 15m or with a surface water inundation area of more than 200 ha.

Moreover, the Decision No.8/2000 (Item No.7 of above) mandates public consultation and community (stakeholder) participation in the process of conducting an AMDAL study from the very beginning of the formulation of TOR of AMDAL study (KA-ANDAL) that also includes the screening and scoping of the EIA study as well, which could be approximated to IEE.

Moreover, this Decision No.8/2000 defines the objectives of public consultation in the AMDAL process into the following 4 items.

1. To protect the public interests
2. To empower the community in decision making on activity plans that potentially would cause significant impacts on the environment
3. To secure transparency in the whole process of AMDAL of the activity plan
4. To create equal partnership climate among all concerned parties thereby respecting rights of all parties to obtain information and requiring all parties to provide information that must be known by other parties who are affected

### (3) Environmental Standards

Conforming to the Article 14 of the new basic environmental law (No. 23/1997) that stipulates the formulation of environmental quality standards, the Government Regulation No.82/2001 (PP82/2001) was published as also noted above under Item (1). This most up to date regulation of 2001 is concerned to the management of water quality and water pollution control and hence has much relevance to this master plan and feasibility study on water resources development and management.

APPENDIX of this regulation specifies the national water quality standards (NWQS) that are in fact environmental water quality standards based on the intended beneficial use of a fresh water body with no distinction being made on the type of water body such as rivers, lakes or groundwater. This new NWQS overrides all similar previous national and regional beneficial use based water quality standards that had been in force. Such overridden standards include the national water quality standards specified as the APPENDIX of Government Regulation No.20/1990 (PP20/1990) and also regional (provincial) water quality standards specified by the Decree No.515/2000 of Governor of Bali.

In fact this new NWQS of 2001 is intended to be the bare minimum quality requirement for the entire Indonesian fresh waters. The provincial governments can set their own standards that could only be more stringent than that of the NWQS and also may include standard values for any additional parameters as appropriate to suit the local requirements. The Provincial Government of Bali is in the process of formulating its own water quality standards based on this new NWQS. Until such time the new provincial standards of Bali become effective this new NWQS is deemed to be applicable at least concerned to those parameters specified in it for the 4 corresponding classes of beneficial uses as given below.

The 4 Classes of beneficial use envisaged by the new NWQS is defined as follows:

**Class I** Raw water for potable (drinking) water supply with treatment and all other beneficial uses of Class II to Class IV

**Class II** Water for contact recreation and all other uses of Class III and Class IV

**Class III** Water for freshwater fishery, livestock farming and the use of Class IV

**Class IV** Water for irrigation use

The new NWQS as of Government Regulation No.82/2001 (PP82/2001) is shown in Table-E.4.

This NWQS was basically used for the evaluation of water quality dealt with in the forgone Section E-1.

**Table-E.4 National Water Quality Standards (NWQS) of Indonesia (2001)**

| Parameter | Unit | Class | | | | Remarks |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | |
| Physical | | | | | | |
| Temperature | °C | Deviation 3 | Deviation 3 | Deviation 3 | Deviation 5 | Temperature deviation from the natural condition |
| TDS | mg/L | 1000 | 1000 | 1000 | 2000 | |
| TSS | mg/L | 50 | 50 | 400 | 400 | To processing for drinking water as conventional, TSS <5000mg/L |
| Inorganic chemistry | | | | | | |
| PH | | 6 - 9 | 6 - 9 | 6 - 9 | 5 – 9 | If naturally outside spanning, determine pursuant to natural condition. |
| BOD | mg/L | 2 | 3 | 6 | 12 | |
| COD | mg/L | 10 | 25 | 50 | 100 | |
| DO | mg/L | 6 | 4 | 3 | 0 | Minimum value |
| Total phosphorus | mg/L | 0.2 | 0.2 | 1 | 5 | |
| NO3 as N | mg/L | 10 | 10 | 20 | 20 | |
| NH3-N | mg/L | 0.5 | (-) | (-) | (-) | To fishery, content of free ammonia for sensitive fish≤0.02 mg/L as $NH_3$ |
| Arsenic | mg/L | 0.05 | 1 | 1 | 1 | |
| Cobalt | mg/L | 0.2 | 0.2 | 0.2 | 0.2 | |
| Barium | mg/L | 1 | (-) | (-) | (-) | |
| Boron | mg/L | 1 | 1 | 1 | 1 | |
| Selenium | mg/L | 0.01 | 0.05 | 0.05 | 0.05 | |
| Cadmium | mg/L | 0.01 | 0.01 | 0.01 | 0.01 | |
| Chromium (VI) | mg/L | 0.05 | 0.05 | 0.05 | 1 | |
| Copper | mg/L | 0.02 | 0.02 | 0.02 | 0.02 | To processing for drinking water as conventional, Cu ≤1 mg/L |
| Iron | mg/L | 0.3 | (-) | (-) | (-) | To processing for drinking water as conventional, Fe ≤ 5 mg/L |
| Lead | mg/L | 0.03 | 0.03 | 0.03 | 1 | To processing for drinking water as conventional, Pb ≤ 0.1 mg/L |

# *Appendices*

# Appendix-1
# Results of Initial Water Quality Survey by JICA

## Appendix-1.1 Results of Initial Water Quality Survey by JICA ( Rivers )-(1/4)

| No | Parameter | Unit | GIS No. of Sampling Location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 59 | 21 | 23 |
| 1 | Temperature | ˚C | 22.2 | 26.0 | 28.0 | 26.6 | 30.0 | 31.5 | 28.2 | 29.6 | 31.8 | 27.6 | 24.1 | 27.0 |
| 2 | pH | - | 7.81 | 2.63 | 7.37 | 7.62 | 7.25 | 7.15 | 7.46 | 7.34 | 7.30 | 7.71 | 6.69 | 6.98 |
| 3 | Conductivity | S/m | 0.01 | 0.02 | 0.04 | 0.02 | 0.03 | 0.04 | 0.04 | 0.04 | 0.07 | 0.03 | 0.05 | 0.01 |
| 4 | DO | mg/L | 6.78 | 5.31 | 6.81 | 6.14 | 1.97 | 3.67 | 5.00 | 3.42 | 2.06 | 5.76 | 2.00 | 6.32 |
| 5 | Turbidity | NTU | 14 | 26 | 32 | 38 | 28 | 22 | 5 | 6 | 46 | 23 | 320 | 195 |
| 6 | BOD | mg/L | 3.72 | 3.55 | 3.58 | 9.86 | 20.70 | 17.82 | 3.70 | 19.10 | 17.7 | 5.60 | 19.80 | 8.95 |
| 7 | $NO_3$ | mg/L | 5.506 | 3.39 | 3.96 | 3.74 | 7.85 | 6.44 | 5.636 | 13.050 | 12.190 | 1.855 | 2.934 | 3.053 |
| 8 | $NO_2$ | mg/L | 0.003 | 0.049 | 0.215 | 0.108 | 0.113 | 0.169 | 0.121 | 0.231 | 0.182 | 0.015 | 0.079 | 0.007 |
| 9 | SS | mg/L | 5.00 | 0.20 | 2.68 | 41.0 | 28.0 | 11.0 | 0.60 | 2.68 | 14.07 | 38.57 | 58.0 | 150.0 |
| 10 | TDS | mg/L | 440 | 140 | 160 | 280.0 | 240.0 | 380.0 | 280 | 280 | 300 | 140.0 | 560 | 680 |
| 11 | CN | mg/L | ND | 0.003 | 0.004 | 0.012 | 0.029 | 0.018 | 0.011 | 0.013 | 0.019 | 0.009 | - | 0.005 |
| 12 | T-N | mg/L | 7.21 | 5.80 | 4.90 | 5.79 | 9.06 | 9.89 | 8.32 | 14.73 | 12.94 | 2.06 | 3.67 | 5.34 |
| 13 | T-P | mg/L | ND | 0.138 | 0.129 | 0.086 | 0.112 | 0.069 | 0.078 | 0.093 | 0.103 | 0.096 | 0.146 | 0.292 |
| 14 | Cl | mg/L | 28.05 | 24.50 | 27.69 | 21.66 | 23.85 | 37.28 | 35.15 | 54.32 | 51.83 | 26.63 | 34.440 | 25.210 |
| 15 | Cd | mg/L | 0.017 | 0.010 | 0.014 | 0.012 | 0.018 | 0.008 | 0.014 | 0.014 | 0.009 | 0.009 | - | 0.020 |
| 16 | $Cr^{6+}$ | mg/L | 0.009 | 0.028 | 0.012 | 0.015 | 0.012 | 0.015 | 0.016 | 0.010 | 0.016 | 0.008 | - | 0.007 |
| 17 | Hg | mg/L | ND | ND | ND | ND | 0.0019 | 0.0006 | ND | 0.0001 | 0.0003 | ND | - | ND |
| 18 | Cu | mg/L | 0.008 | 0.009 | 0.010 | 0.020 | 0.017 | 0.006 | 0.009 | 0.015 | 0.022 | 0.013 | - | 0.015 |
| 19 | Pb | mg/L | 0.056 | 0.063 | 0.082 | 0.080 | 0.077 | 0.064 | 0.043 | 0.074 | 0.038 | 0.008 | - | 0.087 |
| 20 | Zn | mg/L | 0.029 | 0.20 | 0.20 | 0.240 | 0.190 | 0.150 | 0.180 | 0.210 | 0.170 | 0.160 | - | 0.139 |
| 21 | Mn | mg/L | 0.078 | 0.092 | 0.108 | 0.202 | 0.126 | 0.306 | 0.118 | 0.112 | 0.310 | 0.054 | - | 0.166 |
| 22 | Fe | mg/L | 0.356 | 0.537 | 0.812 | 0.979 | 1.783 | 1.984 | 0.406 | 0.430 | 0.911 | 0.436 | - | 0.922 |
| 23 | As | mg/L | ND | 0.0005 | 0.0007 | 0.0003 | 0.0007 | 0.0007 | 0.0012 | 0.0008 | 0.0011 | 0.0008 | - | ND |
| 24 | Fecal Coli | /100ml | 280 | 9,000 | 4,000 | 210,000 | 11,000 | 3,000 | 9,000 | 3,000 | 14,000 | 300 | 4,000 | 11,000 |
| 25 | Coliforms | /100ml | 280 | 23,000 | 23,000 | 1,100,000 | 110,000 | 110,000 | 23,000 | 75,000 | 75,000 | 21,000 | 11,000 | 11,000 |

NOTE :
ND : NOT DETECTED

## Appendix-1.1 Results of Initial Water Quality Survey by JICA ( Rivers )-(2/4)

| No | Parameter | Unit | GIS No. of Sampling Location | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 27 | 30 | 34 | 31 | 33 | 35 | 37 | 38 | 40 | 41 | 43 | 48 | 49 |
| 1 | Temperature | ˚C | 27.7 | 27.2 | 22.6 | 27.3 | 27.2 | 27.3 | 28.7 | 25.1 | 25.10 | 24.1 | 25.6 | 25.8 | 24.2 |
| 2 | pH | - | 7.47 | 7.05 | 6.93 | 7.95 | 7.88 | 7.65 | 6,66 | 7.79 | 7.87 | 7.32 | 6.95 | 7.84 | 7.56 |
| 3 | Conductivity | S/m | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 | 0.05 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.0 |
| 4 | DO | mg/L | 6.70 | 5.89 | 5.86 | 6.49 | 6.04 | 5.90 | 3.99 | 6.40 | 6.68 | 6.22 | 5.23 | 5.38 | 6.78 |
| 5 | Turbidity | NTU | 22.0 | 5.0 | 0 | 0 | 13 | 7.0 | 1.0 | 33.0 | 10 | 8 | 73.0 | 364 | 30.0 |
| 6 | BOD | mg/L | 3.45 | 2.18 | 1.10 | 3.17 | 2.66 | 2.91 | 3.26 | 5.30 | 6.32 | 4.34 | 10.85 | 15.80 | 5.10 |
| 7 | $NO_3$ | mg/L | 4.702 | 2.925 | 0.830 | 2.585 | 2.531 | 11.293 | 5.623 | 3.368 | 8.745 | 3.909 | 2.684 | 3.171 | 2.947 |
| 8 | $NO_2$ | mg/L | 0.010 | 0.025 | 0.060 | 0.009 | 0.025 | 0.026 | 0.024 | 0.007 | 0.002 | 0.002 | 0.013 | 0.011 | 0.008 |
| 9 | SS | mg/L | 2.00 | 9.25 | 1.47 | 2.67 | 9.78 | 19.76 | 4.00 | 30.0 | 29.00 | 25.71 | 50.0 | 180.0 | 27.0 |
| 10 | TDS | mg/L | 760 | 480 | 480 | 960 | 320 | 160 | 380 | 840 | 260.0 | 160.0 | 720 | 320 | 280 |
| 11 | CN | mg/L | ND | 0.003 | 0.001 | ND | - | 0.003 | - | 0.005 | 0.004 | 0.006 | 0.004 | 0.006 | 0.003 |
| 12 | T-N | mg/L | 6.43 | 4.10 | 1.15 | 3.04 | 3.78 | 13.57 | 6.70 | 4.24 | 11.34 | 4.14 | 2.78 | 3.34 | 3.43 |
| 13 | T-P | mg/L | ND | 0.273 | 0.180 | 0.141 | 0.258 | 0.125 | 0.109 | 0.192 | 0.112 | 0.080 | 0.185 | 0.223 | 0.200 |
| 14 | Cl | mg/L | 39.05 | 22.01 | 43.31 | 50.06 | 33.27 | 30.53 | 46.86 | 20.95 | 26.63 | 24.85 | 26.27 | 35.50 | 23.08 |
| 15 | Cd | mg/L | 0.016 | - | 0.003 | 0.007 | - | 0.011 | - | 0.020 | 0.007 | 0.015 | 0.033 | 0.023 | 0.009 |
| 16 | $Cr^{6+}$ | mg/L | 0.008 | - | 0.009 | 0.025 | - | 0.014 | - | 0.005 | 0.009 | 0.011 | 0.003 | 0.009 | 0.005 |
| 17 | Hg | mg/L | ND | - | ND | ND | - | ND | - | ND | ND | ND | ND | ND | ND |
| 18 | Cu | mg/L | 0.012 | - | 0.007 | 0.011 | - | 0.015 | - | 0.029 | 0.010 | 0.012 | 0.047 | 0.151 | 0.010 |
| 19 | Pb | mg/L | 0.092 | - | 0.011 | 0.041 | - | 0.079 | - | 0.160 | 0.009 | 0.051 | 0.210 | 0.134 | 0.023 |
| 20 | Zn | mg/L | 0.410 | - | 0.090 | 0.160 | - | 0.260 | - | 0.185 | 0.080 | 0.180 | 0.203 | 0.137 | 0.097 |
| 21 | Mn | mg/L | 0.087 | - | 0.080 | 0.123 | - | 0.145 | - | 0.281 | 0.121 | 0.012 | 0.270 | 0.751 | 0.154 |
| 22 | Fe | mg/L | 0.284 | - | 0.190 | 0.297 | - | 0.947 | - | 0.141 | 0.663 | 1.012 | 0.212 | 0.942 | 0.172 |
| 23 | As | mg/L | ND | - | ND | 0.0010 | - | 0.0001 | - | 0.0005 | 0.0004 | 0.0004 | 0.0001 | ND | 0.0003 |
| 24 | Fecal Coli | /100ml | 200 | 300 | 2,800 | 300 | 300 | 2,800 | 900 | 4,000 | 700 | 0 | 3,000 | 11,000 | 3,000 |
| 25 | Coliforms | /100ml | 280 | 110,000 | 460,000 | 9,300 | 240,000 | 110,000 | 210,000 | 7,000 | 110,000 | 110,000 | 21,000 | 11,000 | 7,000 |

NOTE :
ND : NOT DETECTED

## Appendix-1.1 Results of Initial Water Quality Survey by JICA ( Lakes, Dam, Springs and Well )-(3/4)

| No | Parameter | Unit | GIS No. of Sampling Location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 51 | 52 | 53 | 54 | 100 | 108 | 112 | 115 | 116 | 117 | 118 | 101 |
| 1 | Temperature | $^oC$ | 25.1 | 23.8 | 23.9 | 24.0 | 29.6 | 25.5 | 25.8 | 22.3 | 28.9 | 27.5 | 26.5 | 27.9 |
| 2 | pH | - | 8.68 | 8.20 | 8.54 | 8.68 | 8.04 | 6.03 | 6.72 | 6.38 | 7.17 | 7.57 | 7.171 | 7.52 |
| 3 | Conductivity | S/m | 0.27 | 0.03 | 0.0 | 0.01 | 0.04 | 0.02 | 0.09 | 0.03 | 0.15 | 0.05 | 1.29 | 0.17 |
| 4 | DO | mg/L | 7.18 | 6.98 | 6.52 | 6.51 | 0.06 | 5.07 | 6.51 | 3.75 | 6.09 | 6.70 | 6.36 | 4.27 |
| 5 | Turbidity | NTU | 1 | 2 | 3 | 2 | 6.0 | 0.0 | 0 | 0 | 2.0 | 0 | 0 | 0.0 |
| 6 | BOD | mg/L | 3.26 | 1.12 | 1.15 | 1.28 | 7.82 | 6.18 | 0.95 | 0.86 | 2.33 | 2.06 | 2.55 | 0.90 |
| 7 | COD | mg/L | 12.97 | 7.98 | 9.12 | 8.12 | 19.08 | 18.16 | 7.06 | 6.12 | 8.79 | 12.21 | 8.38 | 9.10 |
| 8 | $NO_3$ | mg/L | 6.607 | 1.182 | 2.309 | 2.291 | 2.487 | 4.896 | 0.321 | 0.463 | 4.807 | 1.741 | 6.161 | 10.105 |
| 9 | $NO_2$ | mg/L | 0.0004 | 0.002 | 0.002 | 0.003 | 0.007 | ND | 0.002 | 0.001 | ND | 0.012 | ND | 0.747 |
| 10 | SS | mg/L | 4.0 | 7.25 | 32.86 | 19.33 | 6.5 | 1.6 | 1.40 | 0.70 | 1.34 | 2.67 | 6.0 | 5.2 |
| 11 | TDS | mg/L | 2,120 | 130 | 160.0 | 120 | 540 | 420 | 480 | 400 | 1800 | 600 | 10,940 | 884 |
| 12 | T-N | mg/L | 8.79 | 1.30 | 2.54 | 3.02 | 3.12 | 7.01 | 0.37 | 0.502 | 6.43 | 3.81 | 8.12 | 12.23 |
| 13 | T-P | mg/L | ND | 0.040 | 0.057 | 0.016 | 0.154 | ND | 0.104 | 0.156 | 0.068 | ND | ND | 0.009 |
| 14 | Cl | mg/L | 265.54 | 23.08 | 17.75 | 15.62 | 37.28 | 22.37 | 154.43 | 28.76 | 319.5 | 47.93 | 4,331 | 209.45 |
| 15 | Fecal Coli | /100 mL | 28 | 0 | 400 | 300 | 1,400 | 23 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Coliforms | /100 mL | 120 | 15,000 | 3,900 | 24,000 | 2,800 | 75 | 110,000 | 110,000 | 9 | 93 | 43 | 110 |

NOTE :
ND : NOT DETECTED

## Appendix-1.1 Results of Initial Water Quality Survey by JICA ( Wells )-(4/4)

| No | Parameter | Unit | GIS No. of Sampling Location | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 102 | 103 | 104 | 105 | 106 | 107 | 109 | 110 | 111 | 113 | 114 | 119 | 120 |
| 1 | Temperature | $^oC$ | 28.5 | 27.8 | 30.5 | 28.3 | 27.8 | 29.5 | 31.2 | 28.3 | 27.5 | 28.3 | 32.5 | 28.5 | 28.4 |
| 2 | pH | - | 7.47 | 7.26 | 6.69 | 7.14 | 7.27 | 7.33 | 6.91 | 7.66 | 6.90 | 7.58 | 6.95 | 6.95 | 7.48 |
| 3 | Conductivity | S/m | 0.06 | 0.12 | 0.08 | 0.21 | 0.16 | 0.10 | 0.13 | 0.07 | 0.04 | 0.09 | 0.06 | 2.28 | 1.17 |
| 4 | DO | mg/L | 3.65 | 4.82 | 2.84 | 2.06 | 3.12 | 4.04 | 1.36 | 5.16 | 4.10 | 3.54 | 3.13 | 6.41 | 3.23 |
| 5 | Turbidity | NTU | 0.0 | 0.0 | 0.00 | 2.00 | 2.00 | 1.0 | 6.00 | 1.00 | 0 | 0 | 0 | 0 | 0 |
| 6 | BOD | mg/L | 1.30 | 1.30 | 5.15 | 4.50 | 4.06 | 3.95 | 1.70 | 3.22 | 3.48 | 3.51 | 1.04 | 4.54 | 5.06 |
| 7 | COD | mg/L | 11.34 | 11.34 | 25.26 | 18.77 | 11.06 | 17.55 | 12.44 | 18.37 | 18.75 | 10.23 | 7.84 | 25.95 | 29.00 |
| 8 | $NO_3$ | mg/L | 2.158 | 2.734 | 9.732 | 4.509 | 6.369 | 4.717 | 4.316 | 2.289 | 3.079 | 9.636 | 3.873 | 6.280 | 6.786 |
| 9 | $NO_2$ | mg/L | 0.007 | 0.015 | ND | 0.0004 | ND | ND | 0.014 | 0.022 | 0.002 | 0.003 | ND | ND | 0.187 |
| 10 | SS | mg/L | 4.8 | 4.6 | 0.9 | 6.0 | 1.4 | 3.8 | 1.2 | 5.6 | 2.4 | 1.46 | 1.80 | 5.0 | 4.0 |
| 11 | TDS | mg/L | 478 | 786 | 980 | 1,620 | 2,160 | 1,400 | 484 | 840 | 740 | 460 | 400 | 16,840 | 8,260 |
| 12 | T-N | mg/L | 2.66 | 3.76 | 11.65 | 6.86 | 8.11 | 6.09 | 5.02 | 2.46 | 3.77 | 10.730 | 8.10 | 8.33 | 8.59 |
| 13 | T-P | mg/L | 0.123 | 0.208 | 0.063 | ND | 0.087 | 0.119 | 0.182 | 0.115 | 0.177 | 0.208 | 0.056 | ND | ND |
| 14 | Cl | mg/L | 42.60 | 177.50 | 47.22 | 320.92 | 173.95 | 137.39 | 118.93 | 23.08 | 21.30 | 110.74 | 52.90 | 7,348 | 3,106 |
| 15 | Fecal Coli | /100 mL | 30 | 40 | 0 | 11 | 0 | 3 | 70 | 0 | 70 | 1,100 | 0 | 4 | 3 |
| 16 | Coliforms | /100 mL | 640 | 140 | 23 | 20 | 23 | 43 | 640 | 280 | 70 | 120,000 | 900 | 23 | 43 |

NOTE :
ND : NOT DETECTED

# Appendix-2
# Results of Supplemental Water Quality Survey by JICA

## Appendix-2.1 Results of Supplemental Water Quality Survey by JICA

| No | Parameter | Unit | Location No. of River Sampling Location | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1. | Discharge | $m^3$/sec | 3.952 | No flow | 5.872 | 2.275 | 8.955 | 3.258 | 3.212 | 3.514 | 4.185 | 1.454 | 5.716 | 1.319 | 4.544 | 0.886 |
| 2. | Temperature | $^oC$ | 29.2 | 30.4 | 22.4 | 23.9 | 23.3 | 25.5 | 26.1 | 26.6 | 27.8 | 26.3 | 27.8 | 26.5 | 27.6 | 28.0 |
| 3. | pH | - | 7.47 | 7.66 | 8.27 | 8.11 | 8.17 | 7.76 | 7.87 | 6.07 | 7.93 | 8.14 | 8.23 | 7.62 | 7.53 | 7.40 |
| 4. | Conductivity | S/m | 0.04 | 0.28 | 0.02 | 0.02 | 0.02 | 0.02 | 0.2 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 |
| 5. | DO | mg/L | 1.07 | 1.23 | 9.26 | 6.94 | 7.12 | 6.58 | 6.24 | 5.57 | 6.58 | 6.37 | 7.09 | 6.44 | 5.87 | 6.13 |
| 6. | Turbidity | NTU | 6 | 15 | 12 | 12 | 13 | 11 | 31 | 55 | 78 | 8 | 26 | 14 | 14 | 5 |
| 7. | BOD | mg/L | 22.59 | 15.89 | 2.56 | 2.93 | 3.20 | 5.534 | 5.111 | 5.485 | 5.483 | 3.743 | 2.335 | 1.370 | 2.105 | 2.370 |
| 8. | COD | mg/L | 45.46 | 38.72 | 8.25 | 12.40 | 12.70 | 12.65 | 12.35 | 13.20 | 12.80 | 9.250 | 9.921 | 9.010 | 9.135 | 8.251 |
| 9. | $NO_3$ | mg/L | 12.16 | 12.35 | 3.089 | 3.115 | 2.064 | 3.705 | 6.825 | 7.635 | 6.962 | 4.45 | 11.24 | 9.19 | 10.12 | 13.64 |
| 10. | $NO_2$ | mg/L | 0.205 | 1.040 | ND | 0.010 | 0.020 | 0.019 | 0.222 | 0.016 | 0.014 | 0.205 | 0.006 | 0.002 | 0.013 | 0.003 |
| 11. | $NH_3$ | mg/L | 0.163 | 0.012 | 0.018 | ND | 0.025 | 0.012 | 0.219 | 0.326 | 0.136 | ND | ND | ND | ND | ND |
| 12. | SS | mg/L | 34 | 14 | 8 | 0.33 | 1.67 | 11.67 | 4 | 31.90 | 38.5 | 10 | 30 | 11 | 14 | 8 |
| 13. | TDS | mg/L | 320 | 1300 | 200 | 190 | 170 | 210 | 180 | 180 | 190 | 260 | 240 | 200 | 220 | 300 |
| 14. | CN | mg/L | 0.037 | 0.021 | ND | ND | 0.001 | 0.003 | 0.007 | 0.009 | 0.005 | 0.004 | 0.006 | 0.003 | 0.011 | 0.008 |
| 15. | T-N | mg/L | 12.828 | 13.49 | 3.938 | 3.238 | 2.109 | 3.738 | 7.406 | 7.967 | 7.112 | 4.476 | 11.296 | 9.912 | 10.133 | 13.643 |
| 16. | T-P | mg/L | 0.165 | 0.114 | 0.014 | 0.014 | 0.320 | 0.357 | 0.643 | 0.543 | 0.929 | 0.179 | ND | ND | ND | ND |
| 17. | Cl | mg/L | 24.85 | 1420 | 30.18 | 30.18 | 24.85 | 26.63 | 28.40 | 33.30 | 28.40 | 17.75 | 21.30 | 24.85 | 28.40 | 25.82 |
| 18. | Cd | mg/L | 0.024 | 0.022 | 0.012 | 0.009 | 0.010 | 0.017 | 0.011 | 0.019 | 0.012 | 0.010 | 0.016 | 0.019 | 0.017 | 0.013 |
| 19. | $Cr^{6+}$ | mg/L | 0.016 | 0.015 | 0.004 | 0.003 | 0.005 | 0.011 | 0.007 | 0.016 | 0.008 | 0.006 | 0.007 | 0.010 | 0.006 | 0.005 |
| 20. | Co | mg/L | 0.010 | 0.011 | 0.011 | 0.013 | 0.011 | 0.021 | 0.010 | 0.011 | 0.015 | 0.009 | 0.022 | 0.014 | 0.019 | 0.014 |
| 21. | Ba | mg/L | 0.014 | 0.016 | 0.013 | 0.014 | 0.012 | 0.019 | 0.017 | 0.015 | 0.018 | 0.013 | 0.014 | 0.019 | 0.022 | 0.018 |
| 22. | B | mg/L | 0.043 | 0.024 | 0.009 | 0.008 | 0.010 | 0.008 | 0.011 | 0.011 | 0.009 | 0.003 | 0.011 | 0.009 | 0.012 | 0.009 |
| 23. | Se | mg/L | 0.009 | 0.007 | 0.001 | ND | ND | ND | 0.002 | 0.007 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| 24. | Hg | mg/L | 0.0022 | 0.0005 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 25. | Cu | mg/L | 0.021 | 0.023 | 0.011 | 0.007 | 0.009 | 0.016 | 0.011 | 0.014 | 0.013 | 0.010 | 0.014 | 0.010 | 0.022 | 0.014 |
| 26. | Pb | mg/L | 0.058 | 0.027 | 0.017 | 0.015 | 0.017 | 0.026 | 0.049 | 0.064 | 0.058 | 0.019 | 0.023 | 0.019 | 0.021 | 0.020 |
| 27. | Zn | mg/L | 0.197 | 0.117 | 0.014 | 0.024 | 0.118 | 0.211 | 0.244 | 0.207 | 0.207 | 0.020 | 0.020 | 0.011 | 0.013 | 0.010 |
| 28. | Mn | mg/L | 0.240 | 0.096 | 0.072 | 0.080 | 0.070 | 0.185 | 0.130 | 0.249 | 0.138 | 0.132 | 0.504 | 0.316 | 0.344 | 0.132 |
| 29. | Fe | mg/L | 1.215 | 0.948 | 0.234 | 0.725 | 0.611 | 0.258 | 0.826 | 0.853 | 0.830 | 0.199 | 0.772 | 0.405 | 0.524 | 0.200 |
| 30. | As | mg/L | 0.0011 | 0.0014 | ND | 0.002 | 0.001 | 0.001 | 0.003 | 0.0009 | 0.004 | 0.001 | 0.002 | 0.001 | 0.002 | ND |
| 31. | Fecal Coli | /100 mL | 12,000 | 11,000 | 90 | 200 | 500 | 400 | 1,000 | 1,000 | 1,100 | 600 | 400 | 500 | 800 | 1,000 |
| 32. | Coliforms | /100 mL | 140,000 | 60,000 | 300 | 500 | 4,000 | 9,000 | 10,000 | 11,000 | 14,000 | 4,000 | 2,200 | 7,000 | 8,000 | 8,000 |

NOTE :
ND : NOT DETECTED
No flow in Location No.2 (Mati River) is due to tidal backwater effect.

**DIRECTORATE GENERAL OF WATER RESOURCES,**
**MINISTRY OF PUBLIC WORKS**
**PUBLIC WORKS SERVICE, BALI PROVINCE**

# THE COMPREHESIVE STUDY
# ON
# WATER RESOURCES DEVELOPMENT
# AND MANAGEMENT IN BALI PROVINCE
# IN
# THE REPUBLIC OF INDONESIA

## FINAL REPORT
## SUPPORTING REPORT

## [F] AGRICULTURE AND IRRIGATION

**AUGUST 2006**

**JAPAN INTERNATIONAL COOPERATION AGENCY**

**YACHIYO ENGINEERING CO., LTD.**
**NIPPON KOEI CO., LTD.**

THE COMPREHENSIVE STUDY
ON WATER RESOURCES DEVELOPMENT AND MANAGEMENT
IN BALI PROVINCE IN THE REPUBLIC OF INDONESIA

SUPPORTING REPORT (F)
AGRICULTURE AND IRRIGATION

TABLE OF CONTENTS

LIST OF TABLES



LIST OF FIGURES

# F-1. PRESENT AGRICULTURE AND IRRIGATION

According to archeological remains, agriculture in Bali started since 4-5 century, and cultivation of wetland paddy and dry land crops was already practiced at least in 9 century. Bali has a long history of agriculture that is governed by the wetland paddy culture with irrigation. The present conditions of agriculture and irrigation are identified to assess the future water demand in the agriculture sector.

## F-1.1 General Characteristics of Agriculture in Bali

### F-1.1.1 Landuse in Bali

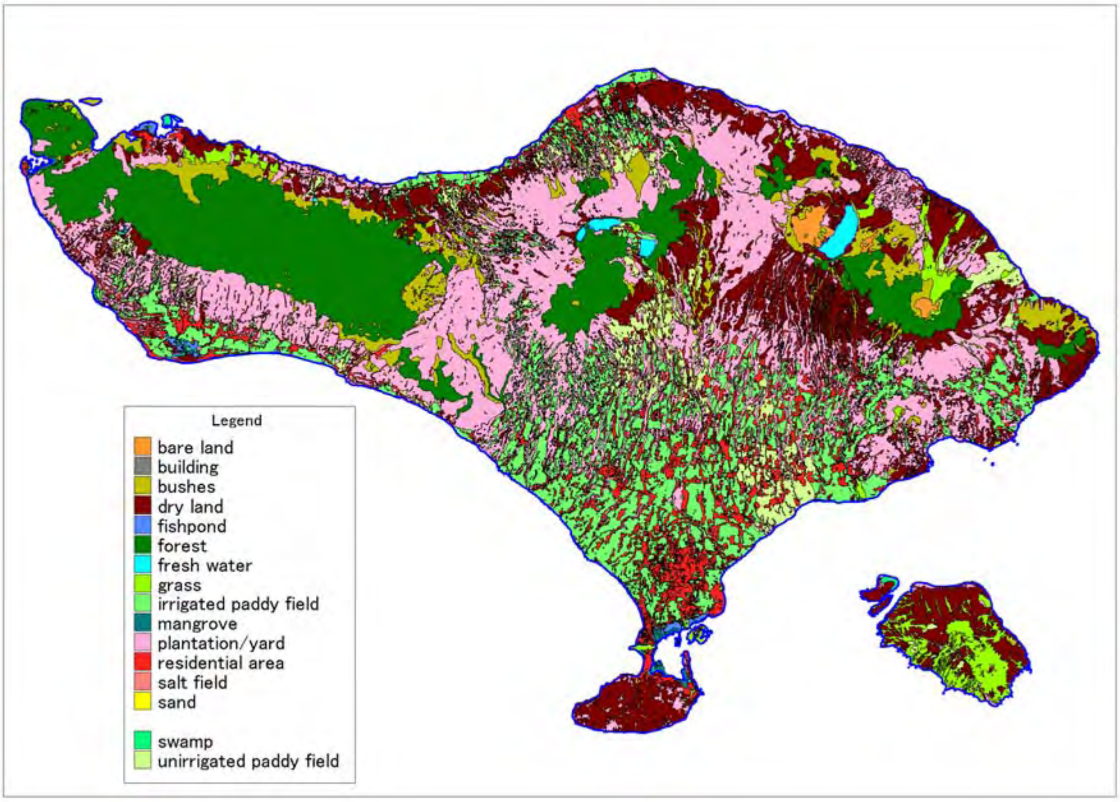
"Bali in Figures 2003 (BPS Statistics of Bali Province)" specifies the area of landuse based on the result of agricultural survey through questionnaire in 2003, while the JICA Study Team conducted the landuse estimate based on Landsat 7 of 2003. Both data are summarized in 6 categories as shown in Table-F.1, and Figure-F.1 shows the result of landuse estimate based on Landsat 7. Figures between two data sources are quite different because of the way to count the landuse, particularly dry land, plantation and forest that are in reality a mixture of several types of landuse. Thus, it is not possible to judge which data reflect the actual conditions but the assessment of landuse can be conducted by comparison of two data. The difference in the provincial area is due to sand area along the coast. In this Study, 5,632.86 km$^2$ is adopted as the total provincial area.

**Table-F.1 Landuse in Bali**

| Category of Landuse | 1) JICA Study | | 2) BPS | |
|---|---|---|---|---|
| | Area (km$^2$) | Ratios (%) | Area (km$^2$) | Ratios (%) |
| Yard and Housing | 555.65 | 9.9 | 451.10 | 8.0 |
| Wetland Paddy Field | 782.45 | 13.9 | 826.44 | 14.7 |
| Dry Land | 1,047.63 | 18.6 | 1,294.86 | 23.0 |
| Plantation | 1,738.73 | 30.8 | 1,272.07 | 22.6 |
| Forest | 1,076.85 | 19.1 | 1,387.09 | 24.5 |
| Others (swamp, pond, sand etc) | 431.54 | 7.7 | 405.10 | 7.2 |
| Total Provincial Area | 5,632.86 | 100.0 | 5,636.66 | 100.0 |

Source: 1) Result of Landuse Estimate based on Landsat 7 of 2003
2) Bali in Figures 2003, BPS Statistics of Bali Province

The agriculture land in Bali consists of the wetland paddy field, dry land and plantation, and occupies approximately 60 % of the provincial land. Data of both sources are consistent in terms of the agricultural land. This implies that almost all arable land has been already cultivated and further extension of farming is very limited. On the other hand, forest coverage varies from 19.1 % to 24.5 %. According to the master plan on forest and land rehabilitation of Bali Province (Forestry Service of Bali Province: *DINAS Kehutanan*), the forest area of Bali is 1,306.86 km$^2$ equivalent to 23.2 % of the provincial area. Therefore, forest coverage is considered ranging within 20 % - 25 % of the provincial area. Anyway the figures are lower than the law (Law No. 41/1999) designation that 30 % of provincial area should be forest. The master plan above aims to increase the forest coverage by afforestation.




Source: Landuse Estimate by the JICA Study Team, based on Landsat 7 of 2003

**Figure-F.1 Landuse Map of Bali**

### F-1.1.2 Agricultural Area

According to Food Crops Agriculture Service of Bali Province, in the last 7 years more than 5,000 ha of paddy field have changed to other functions, such as residential area. The provincial average of decreasing rate is 1.01 %/year equivalent to loss of 870 ha/year. Since factors affecting the decrease in paddy area vary depending on local conditions, the paddy filed in Denpasar, Jembrana and Badung regencies have vanished at much higher rates than the provincial average. On the contrary, the paddy field in Bangli Regency has maintained almost constant.

**Table-F.2 Area Decrease in Paddy Field**

Unit: ha

| No. | Regency | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | Average Decrease Ratio (%/year) |
|---|---|---|---|---|---|---|---|---|---|
| 01 | Jembrana | 8,135 | 8,045 | 7,889 | 7,871 | 7,685 | 7,339 | 7,013 | -2.44 |
| 02 | Tabanan | 23,836 | 23,464 | 23,414 | 23,358 | 23,154 | 22,842 | 22,639 | -0.86 |
| 03 | Badung | 11,578 | 11,473 | 10,816 | 10,705 | 10,619 | 10,413 | 10,334 | -1.88 |
| 04 | Gianyar | 15,323 | 15,227 | 15,203 | 15,169 | 14,966 | 14,945 | 14,937 | -0.42 |
| 05 | Klungkung | 4,049 | 4,049 | 4,016 | 4,013 | 3,985 | 3,965 | 3,932 | -0.49 |
| 06 | Bangli | 2,887 | 2,887 | 2,888 | 2,888 | 2,888 | 2,888 | 2,888 | 0.01 |
| 07 | Karangasem | 7,308 | 7,125 | 7,099 | 7,066 | 7,059 | 7,042 | 7,034 | -0.63 |
| 08 | Buleleng | 11,420 | 11,361 | 11,581 | 11,559 | 11,472 | 11,245 | 11,011 | -0.61 |
| 71 | Denpasar | 3,314 | 3,205 | 3,165 | 3,147 | 3,031 | 2,882 | 2,856 | -2.45 |
| Total | | 87,850 | 86,836 | 86,071 | 85,776 | 84,859 | 83,561 | 82,644 | -1.01 |

Source: DINAS Pertanian Tanaman Pangan Propinsi Bali (Food Crops Agriculture Service of Bali Province)

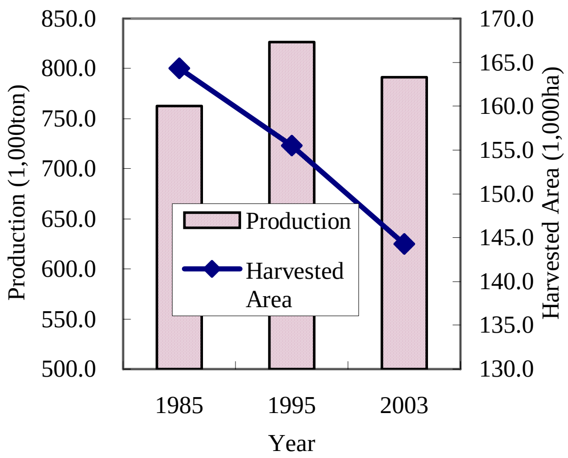
This decreasing tendency is mainly due to urbanization stimulated by tourism. Paddy is a staple food in Indonesia and self sufficiency of paddy is the government policy. In addition to crop production, the paddy field contributes to watershed management, such as flood control by storage of rainfall, recharging groundwater, stabilization of river discharge by delaying runoff, mitigation of drastic temperature change in surrounding area by evapotranspiration, water quality control by nitrogen and phosphorus absorption by paddy, wild animal habitat, and so on. Particularly in Bali, the paddy field is also tourist destination. Therefore, to mitigate the present decreasing tendency of paddy field is one of the policies of Bali Province.

### F-1.1.3 Crop Cultivation

Wetland paddy dominates the crop cultivation in the Bali Province as staple food, followed by secondary food crops, such as maize, cassava, sweet potatoes and so on. Secondary food crops are commonly expressed as *palawija* in Indonesian term, defining non-rice food crops.

#### (1) Paddy

Variation of production and harvested areas of wetland paddy in the last 20 years are shown in Figure-F.2. Significant change is a decrease in harvested area from 164,300 ha in 1985 to 144,300 ha in 2003. This is due to change in landuse from paddy field to non-agriculture use, such as housing.




| Year | Production (1,000 ton) | Harvested Area (1,000ha) | Productivity (ton/ha) |
|---|---|---|---|
| 1985 | 762.8 | 164.3 | 4.60 |
| 1995 | 826.6 | 155.5 | 5.32 |
| 2003 | 791.6 | 144.3 | 5.49 |

**Figure-F.2 Rice Production and Harvested Area in Bali**

Although 20,000 ha of harvested area have vanished in the last twenty years, the annual production of wetland paddy in 2003 (792,000 ton) is larger than production in 1985 (763,000 ton). This is explained by intensification of cropping. Productivity (husked rice) has improved from 4.6 ton/ha in 1985 to 5.5 ton/ha in 2003. Compared to the national average of Indonesia (4.2 ton/ha), rice culture in Bali is well managed.

If 150 kg per capita/year (FAO estimate for rice consumption in Indonesia) is applied, the present production of husked rice in the Bali Province (792,000 ton) is sufficient to feed the whole population in Bali as shown in Figure-F.3. Thus, self sufficiency of staple food has been achieved.

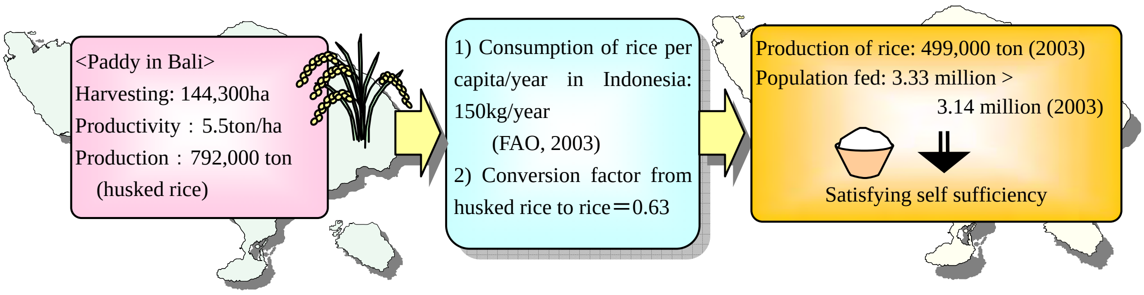



**Figure-F.3 Self Sufficiency of Rice Production**

Table-F.3 shows the spatial variation of rice cultivation. Tabanan Regency famous as rice storage and Gianyar Regency dominate the rice production in Bali, followed by Badung and Buleleng regencies. Since those 4 regencies benefit from water resources, particularly river discharge, paddy cultivation is conducted intensively by irrigation. In 2003, those regencies contribute to 26.2 %, 21.2 %, 14.7 % and 13.0 % of rice production, respectively. As a result, 75 % of rice (almost 600,000 ton) in Bali was produced in those 4 regencies.

**Table-F.3 Rice Production and Harvested Area by Regency**

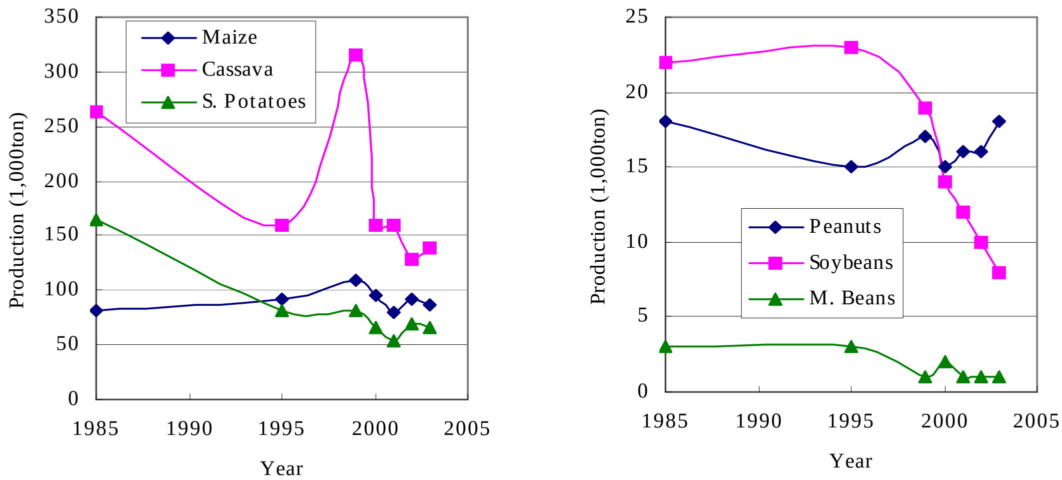
| Regency/ Municipality | | 1985 | | 1995 | | 2003 | | |
|---|---|---|---|---|---|---|---|---|
| | | Harvested Area (ha) | Production (ton) | Harvested Area (ha) | Production (ton) | Harvested Area (ha) | Production (ton) | Production (%) |
| 1 | Jembrana | 12,435 | 60,206 | 10,710 | 57,891 | 8,754 | 50,875 | 6.4 |
| 2 | Tabanan | 42,629 | 198,446 | 44,470 | 231,907 | 39,815 | 207,579 | **26.2** |
| 3 | Badung | 35,172 | 155,641 | 21,310 | 111,887 | 19,924 | 116,489 | **14.7** |
| 4 | Gianyar | 30,289 | 137,835 | 29,720 | 159,857 | 29,562 | 167,420 | **21.2** |
| 5 | Klungkung | 6,524 | 31,852 | 5,164 | 27,752 | 5,747 | 31,763 | 4.0 |
| 6 | Bangli | 5,639 | 27,009 | 5,378 | 29,016 | 5,221 | 26,265 | 3.3 |
| 7 | Karangasem | 9,413 | 41,309 | 11,602 | 61,001 | 10,128 | 57,143 | 7.2 |
| 8 | Buleleng | 22,240 | 104,492 | 21,095 | 115,853 | 19,688 | 102,542 | **13.0** |
| 9 | Denpasar | | | 6,010 | 31,460 | 5,439 | 31,497 | 4.0 |
| Total | | 164,341 | 756,790 | 155,459 | 826,624 | 144,278 | 791,573 | 100.0 |

Source: BPS Statistics of Bali Province
Remarks: In 1985, Denpasar was included in Badung Regency.

### (2) *Palawija*

*Palawija*, which is common Indonesian expression, is defined as non-rice food crops/ secondary food crops. It is cultivated in the paddy field and dry land . In the paddy field, *palawija* cultivation is practiced during the dry season when irrigation water for paddy is not available. It also benefits to avoid crop diseases and low fertility of soil induced by successive cultivation of rice. Food Crops Agriculture Service of Bali Province recommends a cropping sequence of two paddy cultures followed by *palawija* even where the irrigation water is available.

Major *palawija* in Bali are maize, cassava, sweet potatoes and peanuts in terms of production amount. Soybeans used to be one of major *palawija* but are presently cultivated in only limited area like mung beans. Figure-F.4 shows *palawija* productions in the last twenty years. Productions of maize and peanuts are almost constant at 91,000 ton/year and 16,000 ton/year respectively. On the contrary, other *palawija* have a decrease tendency in production. Compared to 1985 productions, cassava production in 2003 is almost half (138,000 ton) and productions of sweet potatoes, soybeans and mung beans have declined more than 30 %. A decrease in *palawija* productions is explained by landuse change of arable land to other functions and diversification of crops considering the market.




S. Potatoes: Sweet Potatoes, M. Beans: Mung Beans
Source: BPS Statistics

**Figure-F.4 Production of Secondary Food Crops**

Unlike paddy, dominant regencies for *palawija* production are Karangasem, Bangli and Klungkung (Table-F.4). Since those regencies have unfavorable conditions for paddy cultivation, such as lack of water and steep land, alternative crops are cultivated. Top producers of major *palawija* in Bali are Karangasem for cassava, Bangli for sweet potatoes and Karangasem for peanuts. In 2003, Karangasem produced 74,700 ton of cassava (54.1 % of provincial production) and 7,600 ton of peanuts (40.9 % of provincial production), while Bangli produced 28,100 ton of sweet potatoes (43.2 % of provincial production).

Buleleng, which is one of leading regencies for rice production, is also the top producer of maize (42.6 % of production in Bali). Maize is cultivated as secondary crop after paddy and in dry land not suitable for paddy. In other leading regencies for paddy production, *palawija* cultivation, except soybean, is very limited. This implies that paddy cultivation is applied to all irrigable land with the first priority, and *palawija* cultivation is a secondary crop in paddy field or a major crop in the dry land.

**Table-F.4 Dominant Regencies of *Palawija* Cultivation**

| Regency/ Municipality | | Production in 2003 | | | | | |
|---|---|---|---|---|---|---|---|
| | | Maize 85,952 ton | Cassava 137,892 ton | S. Potatoes 64,885 ton | Peanuts 18,454 ton | Soybeans 7,836 ton | M. Beans 1,027 ton |
| | | Ratio (%) | Ratio (%) | Ratio (%) | Ratio (%) | Ratio (%) | Ratio (%) |
| 1 | Jembrana | 2.2 | 0.8 | 0.4 | 0.7 | **27.0** | **22.4** |
| 2 | Tabanan | 1.6 | 0.6 | 3.9 | 0.3 | 5.8 | 1.0 |
| 3 | Badung | 1.6 | 2.5 | 9.8 | 6.4 | **27.5** | 0.2 |
| 4 | Gianyar | 1.5 | 3.0 | 9.0 | 6.2 | **10.2** | 0.7 |
| 5 | Klungkung | **18.6** | **22.1** | 3.1 | **26.8** | **14.0** | 0.0 |
| 6 | Bangli | 8.8 | **11.9** | **43.2** | 8.6 | 0.5 | 0.0 |
| 7 | Karangasem | **23.0** | **54.1** | **29.9** | **40.9** | 2.2 | **41.1** |
| 8 | Buleleng | **42.6** | 5.0 | 0.7 | **10.0** | 3.4 | **34.6** |
| 9 | Denpasar | 0.1 | 0.0 | 0.0 | 0.1 | 9.4 | 0.0 |
| Total | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Source: BPS Statistics of Bali Province and calculation by the JICA Study Team
S. Potatoes: Sweet Potatoes, M. Beans: Mung Beans

### (3) Fruit Culture

In Bali, there is a wide variety of fruit culture. If fruits are categorized by production, major fruits whose productions exceed 50,000 ton/year are banana, orange, mango and watermelon as shown in Table-F.5 (fruits production in 2003). According to Bali in Figures 2003 (BPS Statistics), banana and orange amounting to 102,000 ton and 71,000 ton respectively are major commodities of Bali society because of use in a great number of religious ceremonies. Other fruit cultures are durian, sepadile, pineapple, avocado, faidium guajava and melon but their productions are limited to less than 7,000 ton/year.

Bangli and Buleleng regencies dominate the fruit culture in Bali. Bangli Regency contributes to almost 40 % of banana, 65 % of orange and 43 % of jack-fruit productions, while Buleleng Regency leads mango, rambutan and grape productions.

Besides these major regencies, Karangasem Regency produces almost all salacia in Bali. 90 % of watermelon is produced in Jembrana and Denpasar regencies, while papaya culture extends to Gianyar, Buleleng and Bangli regencies.

**Table-F.5 Dominant Regencies of Fruit Culture**

| Major Fruits in Bali | Production in 2003 (ton) | Major Producing Regencies with Contribution (%) | | | | | |
|---|---|---|---|---|---|---|---|
| Banana | 102,158 | Bangli | 39.3 | Jembrana | 24.1 | Buleleng | 17.6 |
| Orange | 71,391 | Bangli | 65.3 | Badung | 24.8 | Buleleng | 8.3 |
| Mango | 55,979 | Buleleng | 85.4 | Bangli | 4.7 | Karangasem | 4.7 |
| Watermelon | 54,089 | Jembrana | 48.6 | Denpasar | 41.4 | Gianyar | 4.8 |
| Salacia | 34,546 | Karangasem | 94.1 | Bangli | 5 | Buleleng | 0.5 |
| Jack fruit | 16,085 | Bangli | 42.6 | Buleleng | 34.2 | Gianyar | 7.6 |
| Rambutan | 13,416 | Buleleng | 74.1 | Gianyar | 7.7 | Tabanan | 4.7 |
| Grape | 11,069 | Buleleng | 100.0 | | | | |
| Papaya | 10,595 | Gianyar | 29.2 | Buleleng | 22.8 | Bangli | 16.1 |

Sources: Bali in Figures 2003, BPS Statistics

Figure-F.5 shows the production variations of major fruits in the last 5 years. Except banana, productions of fruits are almost constant despite the fact that there is yearly fluctuation. However, banana production increased almost double in 2002 compared to the previous three years. Although its production decreased in 2003, production of more than 10,000 ton is still maintained.

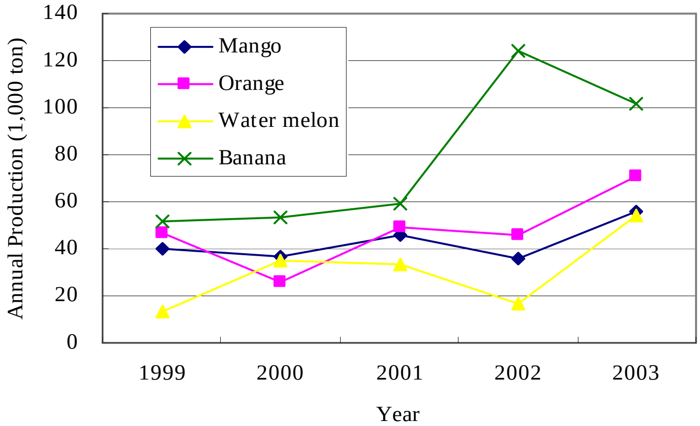



**Figure-F.5 Productions of Major Fruits**

### (4) Horticulture

Table-F.6 shows vegetable culture (horticulture) whose productions exceed 10,000 ton/year and dominant producing regencies based on the data in 2003. As long as productions are considered, cabbage, tomato, chili and mustard green are major horticulture in Bali, followed by onion, string beans, *kangkung* and cucumber. Other vegetables with limited productions (less than 10,000 ton/year) are green beans, potatoes, carrot, spring onions, garlic and egg plant.

Like paddy cultivation, Tabanan Regency dominates horticulture, particularly cabbage, tomato and cucumber whose contributions to provincial production are 68.0 %, 88.1 % and 51.1 % respectively. Tabanan Regency can be named for not only rice but also vegetable storage due to rich agricultural land in terms of water availability, soil fertility and topography.

Since chili is an essential ingredient of Balinese food, its cultivation extends to almost all regencies; however, productions in Tabanan, Karangasem and Klungkung regencies reach to 70 % of provincial production. Another popular vegetable in Bali is *kangkung* (actually very popular in Indonesia) and its dominant regencies are Gianyar and Denpasar followed by Klungkung.

Bangli and Karangasem regencies in eastern region produce almost all shallots, while Jembrana and Buleleng regencies in western region are dominant producers for mustard green. Production of string beans in Karangasem and Klungkung regencies amounts to more than 65 % of provincial production.

**Table-F.6 Dominant Regencies of Horticulture**

| Vegetables | Production in 2003 (ton) | Major Producing Regencies with Contribution (%) | | | | | |
|---|---|---|---|---|---|---|---|
| Cabbage | 51,189 | Tabanan | 68.0 | Bangli | 23.7 | Buleleng | 7.6 |
| Tomato | 43,788 | Tabanan | 88.1 | Bangli | 9.5 | Badung | 0.8 |
| Chili | 40,478 | Tabanan | 32.7 | Karangasem | 23.2 | Klungkung | 15.8 |
| Mustard Green | 35,341 | Jembrana | 65.9 | Buleleng | 28.6 | Gianyar | 2.8 |
| Shallot | 10,845 | Bangli | 80.2 | Karangasem | 18.7 | Buleleng | 0.7 |
| String Beans | 10,822 | Karangasem | 45.9 | Klungkung | 20.6 | Tabanan | 12.3 |
| *Kangkung* | 10,535 | Gianyar | 32.8 | Denpasar | 31.3 | Klungkung | 14.4 |
| Cucumber | 10,321 | Tabanan | 51.1 | Jembrana | 23.6 | Klungkung | 13.9 |

*Kangkung* (Indonesia name): Impomea Reptans in English
Source: Bali in Figures 2003, BPS Statistics

Figure-F.6 shows production variations of major vegetables in the last 5 years. There is a large yearly fluctuation for some vegetables. For example, compared to the pervious year, tomato production decreased to 60 % in 2000, while chili production increased to 160 % in 2003. Cucumber production declined to 60 % of previous year in 2000 but its production recovered in 4 years. *Kangkung* production in 2003 is 5 times more than that in 2001. Fluctuation depends on climatic conditions because horticulture in Bali is generally rain-fed agriculture and irrigation is rarely applied. The market seems not to stimulate extension of horticulture much.

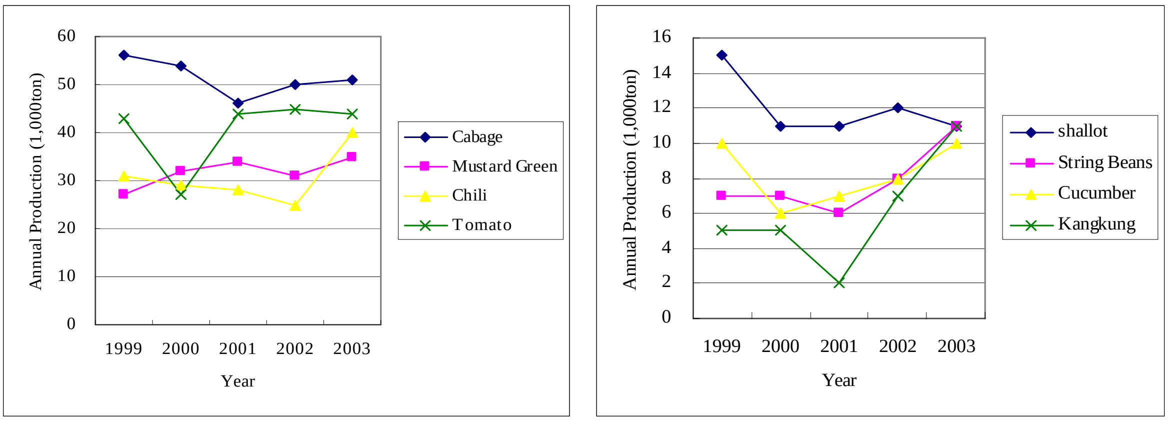



**Figure-F.6 Production of Major Horticulture**

### (5) Estate Crops

Estate crops/plantation in Bali are mainly coconut, coffee (Arabic and Robusta), clove, cashew and tobacco. In general, these crops have a high export opportunity but simultaneously there are many competitors internally and externally. Table-F.7 shows planted area of estate crops in the last twenty years. Coconut and coffee have stable areas; however, areas for other estate crops, particularly vanilla and tobacco, have been decreased. Compared to areas in 1985, areas for vanilla and tobacco in 2003 are limited to only 12 % and 52 %. A decline tendency is considered due to change in demands and result of market competition.

**Table-F.7 Area of Estate Crops**

Unit: ha

| Year | Coconut | Coffee | Clove | Vanilla | Cashew | Tobacco |
|---|---|---|---|---|---|---|
| 2003 | 73,968 | 36,335 | 19,668 | 474 | 10,738 | 849 |
| 2000 | 74,652 | 42,028 | 22,475 | 370 | 15,266 | NA |
| 1995 | 72,534 | 40,000 | 29,940 | 1,836 | 16,470 | 1,964 |
| 1985 | 70,340 | 28,771 | 29,131 | 3,817 | 12,376 | 1,645 |

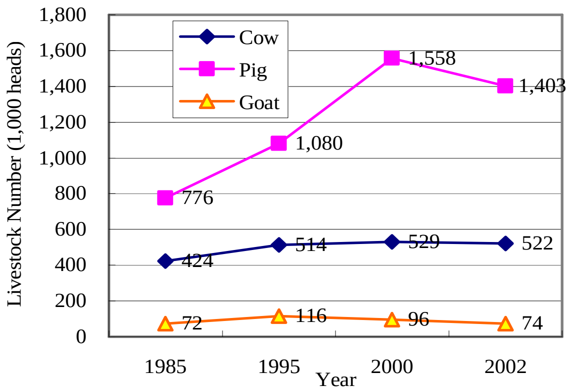
Source: BPS Statistics but original from Estate Service of Bali Province
1) NA: not available, 2) Coconut, coffee and tobacco includes all types.

Estate crops in Bali are mostly owned by smallholders and there are only 4 large plantations. For example, 4 plantations own 835 ha of coconut area only, while the rest of area (more than 73,000 ha) is owned by 200,000 households with an average area of 0.4 ha. Areas for other estate crops also have the same tendency.

### F-1.1.4 Livestock

Cow, pig, goat and poultry dominate livestock in Bali from population point of view. As shown in Figure-F.7, population of pig had steadily increased until 2000 and reached 1,558,000 heads that is double the population in 1985. Although the pig population decreased slightly in 2002, an increase in population explains expansion of demands. On the contrary, populations of cow and goat have been almost constant over the last twenty years at 500,000 and 90,000 heads respectively. Poultry, including chicken and duck, has increased almost double compared to population in 1985 and maintained at 10 million heads. Chicken is major in poultry and duck is always less than 10 % of poultry population. Cow, pig, goat and poultry are for meet production and dairy cow are very rare, ten's order in population.

Unlike major livestock above, buffalo and horse are used for work, such as cultivation of land, transport and so on. In the last twenty years, their population has increased 1.5 times (buffalo) and 2.6 times (horse) more than that in 1985. Sheep is very minor in Bali and its population is at 100's order.




unit: 1,000 heads

| Year | 1985 | 1995 | 2000 | 2002 |
|---|---|---|---|---|
| Buffalo | 5.6 | 7.8 | 11.1 | 8.4 |
| Horse | 0.7 | 0.9 | 1.4 | 1.8 |
| Sheep | 0.4 | 0.1 | 0.2 | 0.6 |
| Poultry | 5,791 | 10,728 | 10,347 | 10,333 |

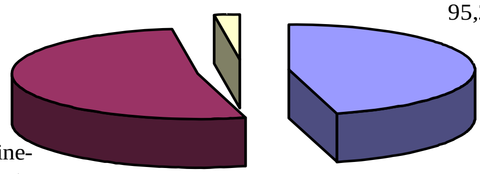
Source: BPS Statistics but original from Livestock Sevice of Bali Province

**Figure-F.7 Livestock Population**

### F-1.1.5 Fishery

Marine fishery dominates the fish production in Bali and its production in 2003 amounted to 204,000 ton equivalent to 97.9 % of the total production. More than half of marine fish production depends on fish cultivation (53.3 %). The fish cultivation is mostly practiced in Klungkung Regency and its share in 2003 reached 95.5 % (103,726 ton), followed by Badung Regency whose share was 4.1 % (4,415 ton). A catch (95,000 ton) is mostly landed in Jembrana, (43.9 %), Denpasar (31.4 %) and Buleleng (8.9 %) because of access to fishing spots and markets.

On the contrary, inland fishery including catch and cultivation contributes to only 2.1 % of total fish production in 2003. Since Bali is benefited from sea, fishery and market are oriented toward marine fishery. Thus, inland fishery is negligibly small in terms of market and production.




Unit: ton

| Fishery Type | | Production in 2003 |
|---|---|---|
| Maine | Catch | 95,223 |
| | Cultivation | 108,593 |
| Inland | | 4,394 |
| Total | | 208,210 |

Source: BPS Statistics but original from Fisheries Service of Bali Province

**Figure-F.8 Fish Production in 2003**

## F-1.2 Irrigation

### F-1.2.1 Agencies associated with Irrigation

There are several central and local government agencies associated with irrigation in Bali, while *subak*, which is the distinct water users association in Bali, manages irrigation water distribution to farmers. Tasks and duties of each governmental agencies and *subak* are summarized in Table-F.8. In each regency and Denpasar city, there are also public works service and food crops agriculture service, and their task and duties are almost same as provincial services but service coverage is limited to regency/city concerned. In general, government agencies are responsible for improvement of irrigation facilities and farming technology. On the other hand, *subak* is responsible for water distribution and cropping in the field.

**Table-F.8 Agencies involved in Bali Irrigation**

| Category | Name of Agency | Tasks and Duties on Irrigation |
|---|---|---|
| Provincial Government / Regency Government | Public Works Service | - O/M of irrigation facilities belonging to government, such as weirs, primary and secondary canals and so on. |
| | Food Crops Agriculture Service | - Agriculture planning<br>- Technology development for farming<br>- Extension service |
| Central Government | Bali Irrigation Project | - Development of irrigation schemes<br>- Rehabilitation of irrigation schemes |
| Private | *Subak* | - Irrigation management, such as water allocation, water rotation, O/M of irrigation facilities<br>- Cropping management, such as determination of cropping schedule, cropping pattern etc.<br>- Traditional/religious ceremonies |

*Subak* is based on the philosophy (*Tri Hita Karana*) that happiness can be fulfilled when the Creator, people and nature are in harmony. Therefore, its activities are related to not only water use but also tradition and religion. This matter is clearly specified in Bali Province local regulations, No.02/PD/DPRD/1972, that defines *subak* as "customary law societies with socio-agrarian-religious nature which were established since long time ago and developed continuously as landholding organizations in the sphere of water distribution and other for rice fields in one irrigation area" (*SUBAK* in Bali, Public Works Service of Bali Province, 1997).

It is said that *subak* has been organized for more than 1,000 years. One of the reasons to explain sustainability of this farmers' society is that it is based on religion/tradition. According to "*Subak* Irrigation System in Bali" (A. Hafied A. Gany, KIMPRASWIL, 2001), the total number of *subak* in Bali increased from 1,193 *subaks* in 1971 to 1,410 *subaks* in 1993. Although the coverage of each *subak* ranges from 10 ha to 800 ha (*Subak Aseman*), an average coverage is 100 ha.

Since the main concern in this section is irrigation, *subak* is discussed from the irrigation point of view. Table-F.9 summarizes the *subak* functions in terms of irrigation. *Subak* delivers irrigation water evenly to all members based on the right to use water and duty in exchange for water use. The duty is commonly compensated by communal works and membership fees. This system is exactly required for water users associations whose formulation has been intended in Indonesia since 1980s; however, its formulation has not progressed well due to farmers feeling of burden. Unlike other water users association, *subak* organization and tasks have been determined by farmers based on a long term practices and have been conveyed generation to generation for 1,000 years. Since the *subak* system is farmers oriented, *subak* members have high motivation to sustain the system.

As long as irrigation water is concerned, *subak* is a good example for water users association. However, urbanization has stimulated a change of paddy field into other functions, resulting in reduction of *subak* number or coverage area. Besides, as water demand of other users increases with urbanization, there is a conflict of water use between *subak* and other users, particularly the domestic water supply. Even if there is excess water due to area reduction of paddy field, *subak* tends to maintain the original volume of water to increase crop intensity to have more production. For farmers' side, it is reasonable to maximize production with irrigation, while the domestic water supply is one of basic human needs and its limited supply hinders the development in area concerned. How to deal with this matter is one of goals of the water resources management plan.

**Table-F.9 *Subak* Functions for Irrigation**

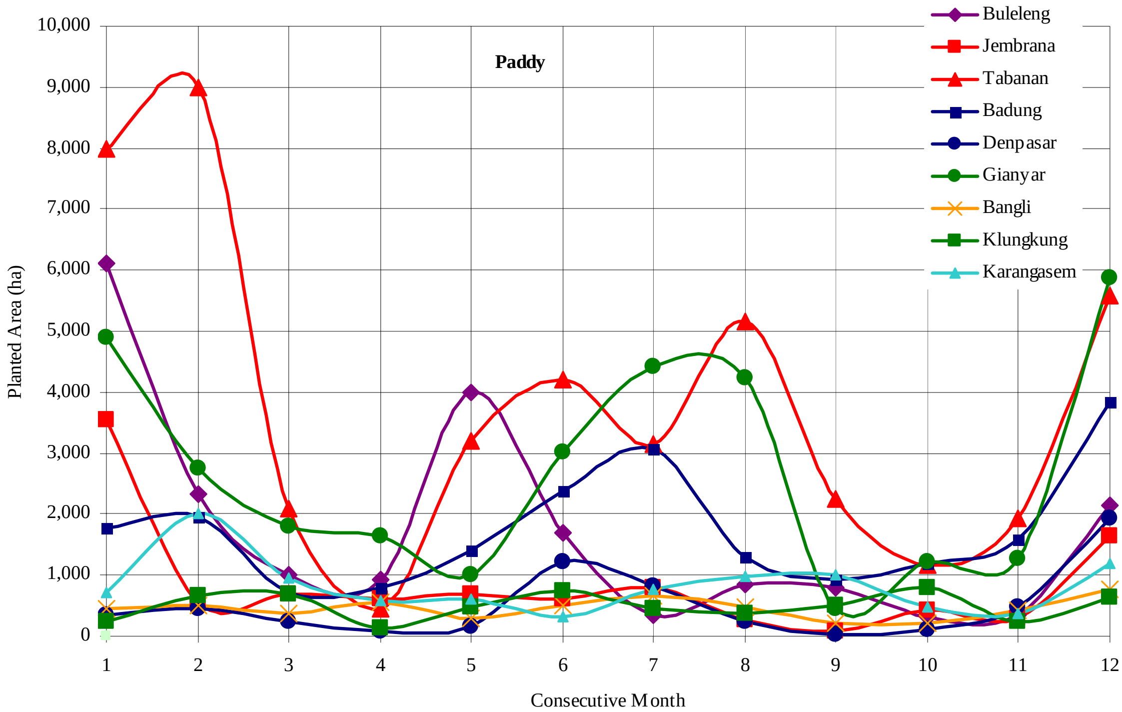
| Category | Functions |
|---|---|
| Organization | - *Subak* is defined as a group of paddy field blocks obtaining irrigation water from the same water resource/management.<br>- The boundary of each *Subak* is usually natural creeks, small valleys, small rivers or village roads.<br>- *Subak* consists of general assembly (*paruman subak*), board (*prajuru subak*) and members (*kerama subak*). General assembly is the highest forum among members to reach consensus, while board is elected by general assembly.<br>- *Subak* functions in accordance with written or unwritten bylaw (*awig-awig*).<br>- *Subak* members are defined as people working paddy fields or involved in *subak* communal activities. |
| Water Distribution | - Water is distributed evenly to all members based on the principal of *ayahan* (the right to use irrigation water) and *ngayah* (free communal work in exchange for water ).<br>- A unit of water requirement is *tektek* that is an amount of irrigation water necessary for one season rice culture with an area up to 1 ha.<br>- One *tektek* unit is measured by area of flow, four fingers (8cm) width and one finger (2cm) depth. For large plots, flow area is determined by multiplying a single *tektek* in proportion to the size of paddy area.<br>- There are three planting and water delivery: 1) *ngulu* (first crop) between November and December, 2) *maongin* (2nd crop) between January and February and 3) *ngesep* (3rd crop) between March and April<br>- Communal work is mainly O/M of irrigation facilities and O/M is shared by government depending on scale of facilities. |
| Drought Measures | There are two alternatives with mutual consensus; 1) reduction of irrigation water supply evenly to all members, 2) rotational water delivery designating plots in the field and crops to be irrigated. |
| Conflicts of Water Use | Conflicts have been solved through discussion among *subaks*, and when traditional weirs are integrated by permanent weirs, federation of *subaks* that share the same weir has been conducted. |

Source: "*SUBAK* in Bali", Public Works Service of Bali Province (*DINAS PU*) and *Subak* Museum, 1997
"*Subak* Irrigation System in Bali", A. Hafied A. Gany, KIMPRASWIL, 2001

### F-1.2.2 Irrigation Crops

Wetland paddy dominates irrigation in Bali and an application of irrigation to other crops, such as fruit culture and horticulture, is negligibly small in terms of area and water consumption. Therefore, cropping pattern and calendar of wetland paddy was analyzed as the irrigation crop in the Bali Province.

Transplanting areas of paddy are available in "Statistics of Agriculture of Food Crops in 2003 (*Statistik Pertanian Tanaman Pangan Tahun 2003*)", Food Crops Agriculture Service of Bali Province. Seasonal variation of transplanting areas explains regional characteristics of cropping calendar. As summarized in Figure-F.9, transplanting of first paddy starts in November/December, and successively its area reaches the peak in January/February. Second paddy and third paddy starts in May/June and in August/September respectively. Although the number of paddy cropping per year is not clear from the figure, the cropping calendar can be identified from Figure-F.9.




***Source: Statistic Agriculture of Food Crops in 2003,***
***Bali Province Food Crops Agriculture Service Office***

**Figure-F.9 Transplanting Areas of Paddy in 2003**

Cropping pattern and intensities in paddy field were identified from the agriculture data from regency. Each year, an agriculture service of regency surveys crop intensity for 13 typical cropping patterns in paddy field. Based on the regency data in 2003, crop intensity and cropping pattern were identified as show in Table-F.10 and successively crop intensity was calculated. There is some discrepancy in crop intensity between the Study Team and Food Crops Agriculture Service of Bali Province. This is due to adjustment of areas with cropping pattern adopted from regencies to total paddy area of regency adopted from Food Crops Agriculture Service of Bali Province. Since the data quite varies depending on the source, the adjustment is often necessary. Considering the yearly variation of cropping pattern, this discrepancy is considered as allowable level.

Crop intensity in paddy field includes not only number of paddy culture/year but also other crop cultures, such as *palawija* and vegetables. The crop intensity in the Bali Province is almost 250 %. Spatial characteristics of cropping pattern are distinct. In Badung, Klungkung, Bangli, Karangasem and Buleleng, 3 cropping (3 paddy/2 paddy + *palawija*) dominate cultivation in paddy field, while 2 cropping (2 paddy and fallow) dominates in Jembrana, Tabanan and Gianyar regencies. The cropping pattern in Denpasar has a wide range due to crop diversification.

## Table-F.10 Cropping Pattern and Crop Intensity in Paddy Field (2003)

| No. | Regency | Paddy Area in 2003 (ha) | Cropping Pattern (% to Total Area) | | | | | | | | | | | | | Crop Intensity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 crops/year | | | | | | 2 crops/year | | | 1 crop/year | | Fallow/Others | | JICA Study Team | DINAS AGRI. |
| | | | 3xP | 2xP+ 1xPL | 1xP+ 2xPL | 2xP+ 1xV | 1xP+ 2xV | 1xP+ 1V+ 1PL | 1xP+ 1xPL | 1xP+ 1xV | 2xP+ F | 1xP+ F | 1xP+ OT | F | OT | | |
| 1 | Jembrana | 7,013 | 1.7 | 11.2 | 8.8 | 0.0 | 0.0 | 0.0 | **35.7** | 0.0 | 17.3 | 14.9 | 5.3 | 2.2 | 2.9 | 191.3 | 186.82 |
| 2 | Tabanan | 22,639 | **27.7** | 3.5 | 0.0 | 3.8 | 0.6 | 0.3 | 0.6 | 2.0 | **54.5** | 5.0 | 0.0 | 1.0 | 1.0 | 226.9 | 227.02 |
| 3 | Badung | 10,334 | **46.5** | **38.8** | 0.3 | 0.1 | 0.1 | 0.0 | 0.9 | 0.0 | 9.8 | 2.0 | 0.0 | 0.4 | 1.1 | 280.8 | 225.82 |
| 4 | Gianyar | 14,937 | **30.4** | 6.8 | 0.8 | 0.6 | 1.3 | 0.0 | 2.4 | 0.0 | **47.1** | 6.8 | 0.0 | 0.0 | 3.8 | 225.5 | 231.95 |
| 5 | Klungkung | 3,932 | 8.4 | **43.2** | **33.0** | 0.0 | 0.0 | 0.0 | 6.8 | 0.0 | 2.2 | 0.0 | 6.4 | 0.0 | 0.0 | 278.2 | 269.07 |
| 6 | Bangli | 2,888 | **39.6** | **36.7** | 7.1 | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 | 12.6 | 0.0 | 0.0 | 0.0 | 0.0 | 283.4 | 251.00 |
| 7 | Karangasem | 7,034 | 4.3 | **33.3** | **46.2** | 0.0 | 0.0 | 0.0 | 5.6 | 0.0 | 4.3 | 3.2 | 0.0 | 0.0 | 3.1 | 274.4 | 243.82 |
| 8 | Buleleng | 11,011 | **29.0** | **38.3** | 6.0 | 0.3 | 3.4 | 0.0 | 13.6 | 0.0 | 8.9 | 0.2 | 0.0 | 0.0 | 0.3 | 276.2 | 213.83 |
| 71 | Denpasar | 2,856 | 8.6 | 12.4 | 9.0 | 15.0 | 0.0 | 8.8 | 4.5 | 12.0 | 15.3 | 4.2 | 0.0 | 0.0 | 10.2 | 229.2 | 262.92 |
| Total | | 82,644 | | | | | | | | | | | | | | 245.5 | 228.10 |

Note: P: Paddy, PL: *Palawija*, V: Vegetables, F: Fallow, OT: Other Landuse but not crop culture
3xP = 3 paddy, 2xP+1xPL = 2 paddy & 1 *palawija*, 1xP+2xPL = 1 paddy & 2 *palawija*, 2xP+1xV = 2 paddy & 1 vegetable, 1xP+2xV = 1 paddy & 2 vegetables
1xP+1xV+1PL = 1 paddy, 1 vegetable & 1 *palawija*
1xP+1xPL = 1 paddy & 1 *palawija*, 1xP+1xV = 1 paddy & 1 vegetable, 2xP+F = 2 paddy & fallow
1xP+F = 1 paddy & fallow, 1xP+OT = 1 paddy & other landuse
F = fallow throughout the year, OT = other landuse

Data Source: Report on Cropping Pattern in Paddy Fields in 2003 from 8 regencies and Denpasar for "Cropping Pattern"
Food Crops Agriculture Service of Bali Province for "Paddy Area in 2003"
"Crop Intensity JICA Study Team": calculation based on the data collected
"Crop Intensity DINAS AGRI": Statistics of Food Crops Agriculture 2003 (*Statistik Pertanian Tanaman Pangan Tahun 2003, DINAS Pertanian Tanaman Pangan Propinsi Bali*)

### F-1.2.3 Irrigation Method

Regarding irrigation in Bali, there are many particular terms that people outside are not familiar with, and some terms have different meanings depending on government agencies. Therefore, some important/common terms used in this Study need to be defined.

<Paddy Field>
The paddy land is locally called as "*sawah*" and mainly planted with wetland "*padi*" (paddy rice) and "*palawija*" (non-rice food crops, such as maize, cassava, sweet potato, soybean and groundnuts).

<Technical Irrigation>
Irrigation facilities from intake to secondary canals are permanent structures that are constructed, operated and maintained by the government. An irrigation scheme is equipped with discharge measurement and water regulation devices. Therefore, intake and conveyance of water can be controlled quantitatively.

<Semi-technical Irrigation>
Irrigation facilities from intake to secondary canals are permanent and semi-permanent structures that are constructed, operated and maintained by the government. An irrigation scheme is equipped with either discharge measurement device or water regulation device. Therefore, intake and conveyance of water cannot be controlled quantitatively.

<Non-technical/Simple Irrigation>
All irrigation facilities are constructed, operated and maintained by the village authority/farmers. Facilities are a mixture of semi-permanent and non-permanent structures without discharge measuring and water regulation devices. As a result, an irrigation scheme conveys water as it flows without any control of water volume.

<Government/Non-government Scheme>
The government scheme is an irrigation scheme whose facilities (from intake to secondary canal) are constructed, operated and maintained by the government. Therefore, technical and semi-technical irrigation belong to the government scheme. On the other hand, an irrigation scheme constructed, operated and maintained by farmers and villages is a non-government scheme.

<*Baku* Area>
*Baku* in Indonesian term is a basic unit that counts only paddy field excluding area for canals, drainage, road, residential area and so on. *Baku* is not necessary to be equipped with irrigation facilities, such as intake, primary canals etc., and is the arable paddy field.

<Potential Area>
This is really a confusing term. It is defined as paddy field equipped with intake and main network (primary and secondary canals) that are constructed, operated and maintained by the government in the case of technical and semi-technical irrigation schemes. Potential can be read as the maximum irrigable area with the existing facilities as long as water is sufficient.

<Functional Area>
Since irrigation in Bali mostly depends on river discharge, areas irrigated fluctuate seasonally. If there were a drought, area irrigated would be smaller than the potential area above. Therefore, the functional area is defined as paddy area actually irrigated out of the potential area.

Paddy area (*sawah*) is available in DINAS PU (Public Works Service of Bali Province) and DINAS PTPP (Food Crops Agriculture Service of Bali Province); however, DINAS PU counts the paddy area in terms of irrigation facilities, while DINAS PTPP counts the paddy area actually cultivated. Besides, different use of the above terminology makes the paddy area more complicated. Therefore, the total paddy areas in Bali between 2 agencies deviate more than 10,000 ha. Through the discussion with DINAS PU and DINAS PTPP, the present paddy area has been determined as shown in Table-F.11.

Table-F.11 summarizes physical areas of paddy field but not transplanting/seeding areas. Potential area is defined as the maximum irrigable area in terms of irrigation facilities. It implies that an application of irrigation can extend to 94,898 ha as long as there is sufficient water. However, in 2003, 82,644 ha of paddy field out of 94,898 ha (potential area) were cultivated, including paddy and other crops, such as *palawija* and vegetables. Overlaying Table-F.10, 2.5 % of the total paddy area equivalent to approximately 2,100 ha was used as fallow/other functions. But most of the paddy area (97.5 %) was cultivated for at least 1 paddy. Irrigation is normally applied to only the paddy culture in Bali. Therefore, more than 80,000 ha of paddy field were irrigated in 2003.

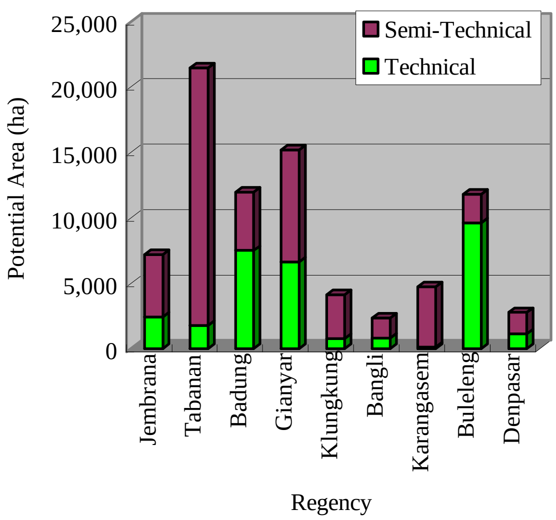
In average, 86 % of irrigable paddy field belong to the government schemes and have either technical or semi-technical irrigation system, while non-government schemes with primitive irrigation system is limited to 14 %. It means that an improvement of irrigation system has extended at high rate and this is one of the reason that Bali has high productivity of rice, 5.5 ton/ha.

**Table-F.11 Present Area of Paddy Field**

| Regency | Potential Area (ha) | | | Functional Area (ha) |
|---|---|---|---|---|
| | Gov. | Non-Gov. | Total | |
| Jembrana | 7,195 | 1,849 | 9,044 | 7,013 |
| Tabanan | 21,464 | 1,997 | 23,461 | 22,639 |
| Badung | 11,961 | 106 | 12,067 | 10,334 |
| Gianyar | 15,187 | 2,022 | 17,209 | 14,937 |
| Klungkung | 4,126 | 304 | 4,430 | 3,932 |
| Bangli | 2,334 | 957 | 3,291 | 2,888 |
| Karangasem | 4,714 | 3,710 | 8,424 | 7,034 |
| Buleleng | 11,807 | 2,403 | 14,210 | 11,011 |
| Denpasar | 2,762 | 0 | 2,762 | 2,856 |
| Total | 81,550 | 13,348 | 94,898 | 82,644 |

Gov.: Government Scheme Non-Gov.: Non-government Scheme Functional Area: paddy area cultivated
Source: Public Works Service of Bali Province for “Potential Area” in 2004
Statistics of Food Crops Agriculture in 2003 (Food Crops Agriculture Service of Bali Province) for “Functional Area” in 2003

Figure-F.10 shows ratios of technical and semi-technical irrigation systems in government schemes. Although the data describes ratios of irrigation systems in 2000, it is assumed as the present system classification. More than 40 % of irrigation systems are the technical in Badung, Gianyar, Buleleng and Denpasar, while almost all systems are the semi-technical in Tabanan and Karangasem (more than 90 %).




Potential Area (Government Scheme)

| | System (%) | | Area Total (ha) |
|---|---|---|---|
| | Technical | Semi-Technical | |
| Jembrana | 33.4 | 66.6 | 7,195 |
| Tabanan | 8.3 | 91.7 | 21,464 |
| Badung | 62.6 | 37.4 | 11,961 |
| Gianyar | 43.5 | 56.5 | 15,187 |
| Klungkung | 18.8 | 81.2 | 4,126 |
| Bangli | 34.2 | 65.8 | 2,334 |
| Karangasem | 2.7 | 97.3 | 4,714 |
| Buleleng | 81.5 | 18.5 | 11,807 |
| Denpasar | 40.7 | 59.3 | 2,762 |
| Total | 37.6 | 62.4 | 81,550 |

Source:
System (%): "Rekapitulasi Daftar Inventarisasi Jaringan Irigasi Pemerintah", DINAS PU, 2002
Area Total: DINAS PU in 2004

**Figure-F.10 System Classification of Government Potential Area**

Table-F.12 specifies the water resources of irrigation in 2000. Although the area irrigated by each water resources is unknown, it can be concluded that dominant water resource of irrigation is surface water (river water) because only 8 wells are utilized for the government schemes that cover 86 % of provincial paddy field. Since the non-government scheme is normally at small scale with primitive infrastructures, their water resources include river, groundwater and even spring water. Groundwater use for irrigation is limited to Jembrana and Buleleng regencies.

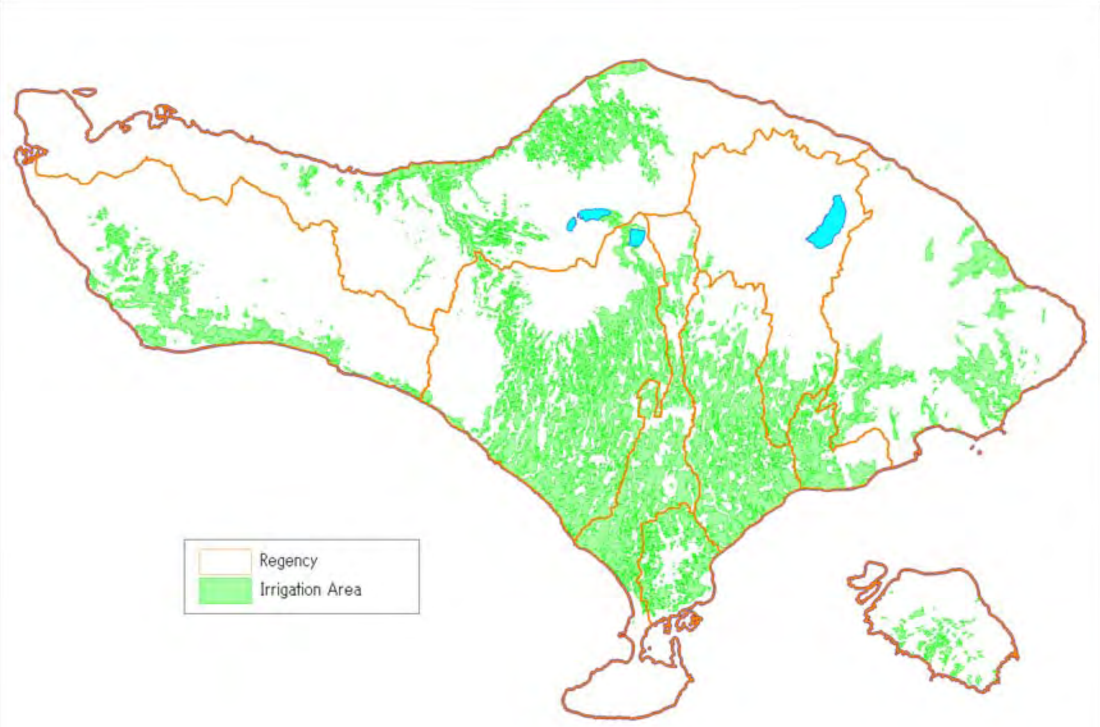
**Table-F.12 Water Resources of Irrigation**

Unit: number of use

| Regency | Government | | Non-Government | | |
|---|---|---|---|---|---|
| | River | Ground water | River | Spring | Ground water |
| Jembrana | 34 | 8* | 17 | 2 | 14 |
| Tabanan | 95 | 0 | 123 | 22 | 0 |
| Badung | 19 | 0 | 0 | 6 | 0 |
| Gianyar | 44 | 0 | 78 | 6 | 0 |
| Klungkung | 20 | 0 | NA | NA | NA |
| Bangli | 27 | 0 | 11 | 1 | 0 |
| Karangasem | 49 | 0 | 72 | 16 | 0 |
| Buleleng | 47 | 0 | 102 | 20 | 2 |
| Denpasar | 12 | 0 | 0 | 0 | 0 |
| Total | 347 | 8* | 403 | 73 | 16 |

River: number of weirs/free intakes Groundwater: number of wells, *: deep wells Spring: number of springs
Source: “Rekapitulasi Daftar Inventarisasi Jaringan Irigasi Desa", DINAS PU (Public Works Service of Bali Province), 2002, but the data in 2000

Although exact boundaries of irrigation schemes (a group of paddy field using the same water resources, such as weir, free intake, well etc.) or locations of irrigation schemes are not available, there is a map to show the extension of wetland paddy field. As shown in Figure-F.11, most of the paddy field is located extensively in Tabanan, Badung, Gianyar and Buleleng regencies and this extension is consistent with figures in Table-F.11 that the total area of paddy field in these 4 regencies covers 70 % of the provincial functional area.




Source: Public Works Service of Bali Province

**Figure-F.11 Wetland Paddy Field in Bali**

### F-1.2.4 Irrigation Rehabilitation and Development

Since 1980s, tremendous rehabilitation works of irrigation facilities have been continuously conducted, using internal and external funds. For example, the Bali Irrigation Sector Project funded by ADB (Asian Development Bank) loan was conducted for 10 years from 1981 to 1989. APBN (national budget) has also applied continuously to improve irrigation facilities. Rehabilitation works improve irrigation efficiency by means of upgrading structures, aiming improvement of crop intensity, crop productivity, and water management. As a result of rehabilitation works, the government scheme covers 86 % of paddy field with technical and semi-technical irrigation system.

Recently, two projects, “Decentralize Irrigation System Improvement Project in Eastern Region of Indonesia” and “Sustainable Development of Irrigated Agriculture in Buleleng and Karangasem”, are ongoing. Those projects intend not only rehabilitation but also development of new irrigation schemes using groundwater. However, as shown in Table-F.13, the target area of new irrigation schemes is at the order of several hundred ha. It means that the possible area for a new irrigation scheme is very limited in terms of availability of arable land and water resources.

## Table-F.13 Recent Projects of Irrigation Rehabilitation and Development

| Project Name | Decentralize Irrigation System Improvement Project in Eastern Region of Indonesia | Groundwater Development Project for Irrigation and Drinking Water in North Bali | Sustainable Development of Irrigated Agriculture in Buleleng and Karangasem |
|---|---|---|---|
| Budget Source | JBIC Loan IP-509 | European Union (EU) | European Union (EU) |
| Executing Agency | Directorate General of Water Resources | Bali Irrigation Project | Bali Irrigation Project |
| Period | 2003 – 2007 (ongoing) | 1993 – 1999 (completed) | 2003 – 2006 (ongoing) |
| Scope | 1) Irrigation improvement for existing schemes constructed in 1980s by APBN (national budget)<br>2) Groundwater development for new irrigation schemes<br>3) Establishment/strengthening of WUAs | 1) Mapping, groundwater study<br>2) Well and pipe networks construction<br>3) Agriculture development<br>4) Management information system | 1) Establishment of irrigation system for 15 production wells drilled in Phase I.<br>2) Drilling of 9 wells with irrigation system<br>3) Re-drilling of 2 wells which has a technical problem (discharges < 10 liter/sec) |
| Site/<br>Water Resources | The project site is selected from the followings after the study.<br>Regency / River / Study Area (ha)<br><Irrigation Improvement><br>1) Jembran Dava 1,047<br>2) Tabanan Ye Hoo 2,488<br>3) Badung Ayung 888<br>Sungi 3,999<br>4) Gianyar Sangsang 888<br>5) Klungkung & Bangli Bubuh 702 & 948<br>6) Karangasem Unda 1,932<br>7) Buleleng Saba 1,915<br><Groundwater Development><br>1) Jembrana 150<br>2) Karangasem 100<br>3) Buleleng 150 | - Project areas spread in Buleleng and Karangasem Regencies.<br>- The groundwater development study was conducted in 90 locations with a total area of 1,500 ha.<br>- After the study, 15 production wells with irrigation system and 15 production wells without irrigation system were constructed.<br>- 15 locations for irrigation are 13 in Buleleng Regency and 2 in Karangasem Regency.<br>- The total service area of irrigation is 240 ha. | This is a continuation project of NBGIWSP (Groundwater Development Project for Irrigation and Drinking Water in North Bali)<br>- Irrigation systems for 15 production wells drilled in Phase I: 12 locations in Buleleng and 3 locations in Karangasem<br>- 9 production wells with irrigation system: 4 locations in Buleleng and 5 locations in Karangasem<br>- Re-drilling of 2 wells in Buleleng |
| Total Project Area (ha) | - Irrigation Improvement: 9,920 ha<br>- Groundwater Development: 500 ha | Irrigation development: 240 ha | |
| Data Source | Inception Report on Consulting Services for DISIMP, October 2003, Nippon Koei, DGWR | The Activity Summary of Groundwater Development, March 2000, Bali Irrigation Project | Project Summary |

JBIC: Japan Bank for International Cooperation

# F-2. AGRICULTURAL WATER DEMAND

In general, agricultural waters to be evaluated for water resources development are irrigation, water consumption by livestock and inland fish culture. However, inland fishery including both catching and culture is negligibly small (2 % of provincial fish production). Besides, water for livestock relies on small ponds/shallow wells at small scale. Therefore, irrigation water that dominates agriculture water in Bali is examined to estimate the water demand.

## F-2.1 Projection of Future Agriculture

To estimate water demand until the target year, 2025, it is necessary to project future agriculture in Bali. Based on two important agriculture plans and analysis of agriculture trend in the past, the projection and assumptions of future agriculture in Bali were made.

### (1) Spatial Plan

"Revision of Regional Spatial Plan of Bali Province, 2003-2010, Provincial Regional Development Agency: *BAPPEDA* (herein after referred as the spatial plan)" aims to optimize the utilization of potential agriculture lands, specifying the planning policy for the wetland and dry land as described below.

1) Wetland

- Maximum utilization of paddy field with irrigation facilities, particularly Tabanan, Badung, Gianyar, Jembrana and Buleleng regencies, where paddy cultivation is intensively conducted.
- Intensification of cultivation, such as improvement of productivity
- Protection of paddy fields from change in landuse, such as residential areas, in accordance with Minister Decree of Home Affairs No. 410-1851 dated on June 15, 1994, stipulating that wetlands/technical irrigation areas shall not be changed to other functions.

2) Dry Land

- Extension of cropping, such as *palawija* and horticulture, to the potentially arable land
- Application of *palawija* cultivation in the paddy field during the dry period
- Promotion of short growing period horticulture with high economic value
- Designation of *palawija* cultivation to each regency:
  Maize, soybean and peanut in Bangli, Karangasem and Buleleng regencies
  Cassava, sweet potatoes and potatoes in other regencies except Denpasar

### (2) RENSTRA

"Strategy Plan on Food Crops Agriculture in Bali Province, 2004-2008 (herein after referred as RENSTRA)" was formulated by Food Crops Agriculture Service of Bali Province (*DINAS Pertanian Tanaman Pangan Propinsi Bali*) in accordance with the spatial plan. RENSTRA is a short term plan, while the spatial plan is a regional long-term plan. RENSTRA specifies the policy and target to mitigate issues associated with agriculture.

1) Issues

- Small land tenure: 55 % of the total farm households have less than 0.5 ha of agriculture land.
- Decrease in paddy area: Paddy area in Bali has been decreasing at the rate of 1.01 %

(approximately 870 ha)/year in average during 1997-2003.
- Lack of irrigation water during the dry season
- Lack of labors (mostly from outside Bali), particularly during the harvesting time
- Limited financial capability
- Organism disease
- Price fluctuation (very low price during the harvesting time)
- Lack of agribusiness

2) Policy

- Intensification of farming, such as improvement of crop productivity and quality, rehabilitation of irrigation facilities, market oriented crop culture, diversification of crops, increase in farmers income
- Development of high quality food crop commodities

3) Target

- To mitigate the decreasing ratio of paddy field at 0.45 % during 2004-2008
- To improve paddy production (dry unhusked rice) from 5.509 ton/ha in 2004 to 5.550 ton/ha in 2008
- To improve the annual production of *palawija* at several % depending on crops
- To promote high yield, quality and market competitive varieties of horticulture
- To develop horticulture agro-business
- To improve production of horticulture

### (3) Future Agriculture

Based on the two plans and past trend analysis regarding agriculture, the followings are most likely pictures of future agriculture in Bali.

1) As discussed in Chapter 1, the area of paddy field (wetland paddy) tends to decrease. In the last 7 years (1997-2003), 1.01 % of paddy field in Bali Province were annually changed to other uses. This reduction is mainly due to urbanization stimulated by development of tourism. As a result, the reduction rates in Denpasar and Badung regencies where are the center of tourism business are 2.45 %/year and 1.88 %/year respectively, while those in other regencies are less than 1.0 %/year, except Jembrana Regency (2.44 %/year). Although the spatial plan and RENSTRA aim to protect the paddy field from landuse change, it is not realistic to achieve this goal immediately because of expansion of tourism sector. It will probably take some period to settle the paddy area decrease.

2) Productivity of wetland paddy in Bali (5.5 ton/ha) is already high compared to the national average (4.2 ton/ha). Ideal production of paddy rice is 8 ton/ha; however, to reach the ideal takes a long time with sophisticated farming and irrigation management. Thus, an improvement of paddy productivity is considered to continue gradually.

3) New irrigation scheme will be limited at small scale with mainly groundwater development because almost all irrigable land has been already utilized as wetland paddy field.

4) Crop diversification will progress and selection of crop culture will be market oriented. Since the paddy culture will be maintained as staple food, *palawija* will be subject to change into horticulture/fruit culture. However, *palawija* is also important as non-rice food crop. Thus, at least certain area of *palawija* to satisfy demands will be maintained.

5) Potential arable dry land will be utilized for *palawija*/horticulture/fruit culture but without irrigation.

### F-2.2 Irrigation Potentials

Irrigation potential areas were examined in terms of soil properties and climate, and successively the possibility to extend further irrigation areas was examined.

#### F-2.2.1 Soil Properties

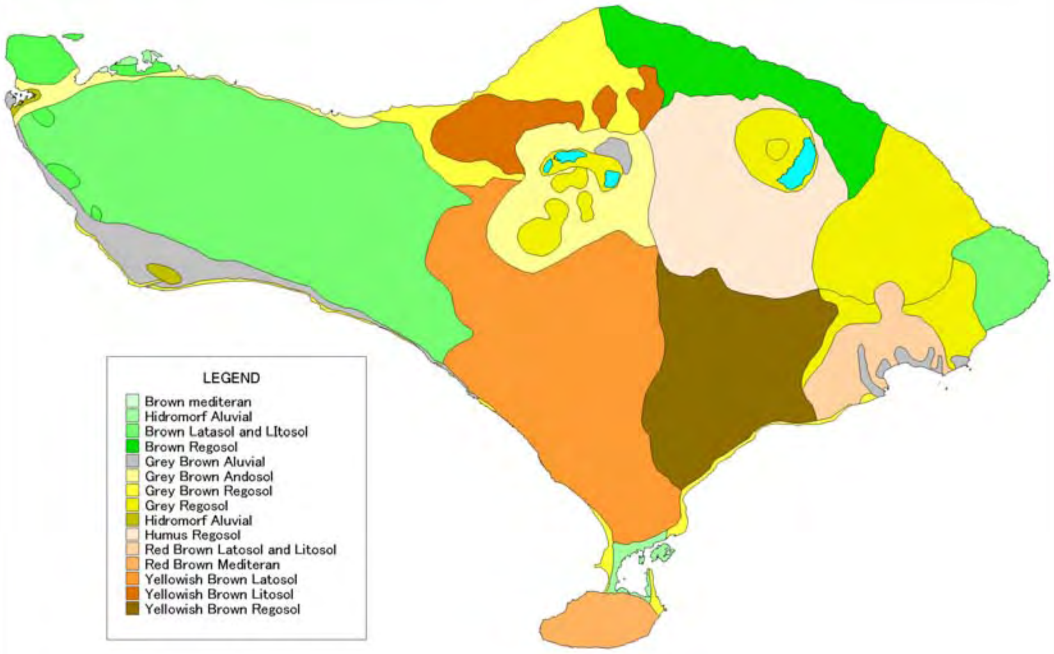
Soil map to discuss soil characteristics in terms of agriculture potential, is not available in the Bali Province. Although an available soil map (Food Crops Agriculture Service of Bali Province, 1970) is not in details, at least spatial variation of major soil can be identified. According to the available soil map (Figure-F.12), the dominant soil in Bali is Latosol lying within the elevation of 0 m to 1,400 m in Badung and Tabanan regencies with an area of 2,310 $km^2$ (41 %). Another dominant soil is Regosol extending on elevation of 0 m to 1,300 m in the eastern part of Bali Island (Badung, Gianyar, Bangli and Klungkung regencies) with an area of 2,250 $km^2$ equivalent to 40 % of the total provincial area. Besides, there are Mediteran, Alluvial and Andosol with an area of 360 $km^2$ (6 %), 275 $km^2$ (5 %) and 230 $km^2$ (4 %) respectively.

**Table-F.14 General Texture of Soils in Bali**

| Soils | Texture | Materials |
|---|---|---|
| Latosol | Medium | Ash, Ash-Silt, Ash-Sand |
| Regosol | | |
| Andosol | Fine | Silt, Silt-Clay, Silt-Sand |
| Alluvium | Coarse | Sand, Sand-Clay |
| Mediteran | | |

Source: "*Revisi Rencana Tata Ruang Wilayah Propinsi Bali 2003 – 2010*", *Bappeda*

Latosol, Regosol, and Andosol are usually dominated by volcanic materials, such as volcanic ash and pyroclastic material in silt, sand and gravel that are usually very fertile. In general those soils have saturation zone at least 20 cm – 50 cm from the surface. Therefore, soils in Bali are suitable for agriculture, particularly paddy cultivation. Latosol and Regosol as well as Alluvium and Mediteran are suitable also for dry land crops.




Source: Food Crops Agriculture Service of Bali Province, 1970

**Figure-F.12 Soil Map in Bali**

### F-2.2.2 Climate

Since the details are discussed in "Hydrology" section in this Study, climate in Bali is examined in agricultural point of view. Monthly mean temperatures in land lower than altitude of 1,200 m range 20-27 $^{o}$C with very small seasonal fluctuation and categorized as warm. Humidity increases in the direction from sea to inland, ranging 70-95 % with seasonal variation of less than 10 %, resulting in humid climate. Wind velocity is categorized light to moderate. Annual average rainfall varies from 1,000 mm to 3,000 mm depending on altitude.

In general, climate factors in Bali are suitable for agricultural practices. Seasonal and spatial variations of rainfall require proper selection of crops and cropping calendar for rain-fed agriculture in the dry land, while irrigation is necessary in the paddy field during the dry season.

### F-2.2.3 Sites for Future Irrigation Projects

Soil and climate factors in Bali are basically suitable for agriculture practices, and seasonal variation of rainfall requires irrigation. Major factors limiting the area of irrigation are steepness of land and river discharge because irrigation mostly relies on surface water. As a result, mountainous areas lying from the west to east of Bali Island are preserved for forest, and irrigation area is very rare in the north-eastern Bali (north of Karangasem and east of Buleleng regencies). On the contrary, irrigation agriculture is intensively and extensively practiced in the south of Bali (Tabanan, Badung and Gianyar regencies).

Almost all irrigable land in Bali has been cultivated for paddy. According to "Statistics of Food Crops Agriculture in 2003 (Food Crops Agriculture Service of Bali Province)", possible areas remained for paddy culture are very limited area, 239 ha in Klungkung and 84 ha in Karangasem. Since the potential arable land for new irrigation schemes is very limited, the crop production and intensity are improved by intensification of framing.

Paddy dominates crop culture and irrigation in Bali, and there is no room to develop new paddy fields. Although it is possible to increase the crop intensity of paddy culture with water resources development, particularly storage facilities, the surface water development at the large scale is not feasible in terms of economic point of view, as long as only irrigation is targeted. Thus, the crop intensity should be increased by the irrigation rehabilitation works improving the irrigation efficiency to minimize the water loss. The residual water benefits to not only the crop intensity but also irrigation on the dry land for fruit culture and horticulture.

Recently, groundwater development has been introduced to irrigate fruit culture/horticulture at a small scale in Jembrana, the eastern part of Buleleng and the northern part of Karangasem. It is effective to the rural development and crop diversification. Thus, the small scale groundwater development will extend, but its area and water consumption will be very small compared to paddy irrigation.

### F-2.3 Parameters to Estimate Irrigation Water Demand

Irrigation water for wetland paddy is a function of crop water requirement (ETcrop), effective rainfall (70%$R_{80}$), irrigation efficiency (E), percolation (P) and farming conditions, such as land preparation (LP) and water layer replacement (WLR). Besides, cropping calendar and crop intensity affect the irrigation water. The definition and determination of each factor are discussed in the following section and an image of irrigation water is show in Figure-F.13.

Irrigation Water Requirement (Wetland Paddy) =

$$(ETcrop + P + LP + WLR - 70\% \, R_{80})/E$$

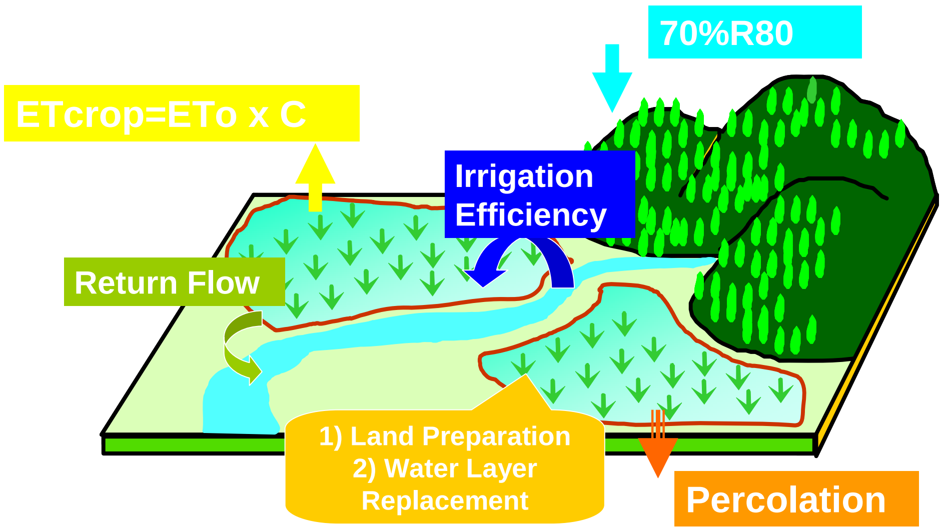



**Figure-F.13 Conceptual Image of Irrigation Water**

#### F-2.3.1 ETcrop

Crop water requirement (ETcrop) is evapotranspiration of a disease-free crop grown in optimum conditions of soil fertility, water and production potential under given environment. It is a function of reference crop evapotranspiration (ETo: formerly defined as potential evapotranspiration) and crop coefficient (kc). Penman-Monteith equation was adopted to calculate ETo, while kc was obtained from "FAO Irrigation and Drainage Paper 24".
The Modified Penman method used to be popular to estimate the reference crop evapotranspiration; however, many studies show overestimate of the Modified Penman and

superior result of the Penman-Monteith method which considers the stomatal resistance of crop canopy and conducts a better simulation of wind and turbulence effects. As a result, the Penman-Monteith has been recommended by FAO. Penman-Monteith method defines the reference crop evapotranspiration as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance and albedo, closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water (Smith M., Allen R. and Pereira L., 1997, Revised FAO Methodology for Crop Water Requirements).

As long as maximum and minimum temperature, relative humidity, surface wind velocity and sunshine hours are available, the Penman-Montheith method provides the most satisfactory results of ETo computation, based on its wide application all over the world. Therefore, applying the Penman-Montheith method, ETo (reference crop evapotranspiration) was computed. The basic equation of the Penman-Montheith method is as follows.

$$ET_O = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T + 273} U_2\left(e_a - e_d\right)}{\Delta + \gamma\left(1 + 0.34U_2\right)}$$

where:

- $ET_o$: reference crop evapotranspiration (mm/day)
- $R_n$: net radiation at the crop surface ($MJ/m^2/day$)
- G: soil heat flux ($MJ/m^2/day$)
- T: average air temperature ($^oC$)
- $U_2$: wind speed measured at 2 m height (m/sec)
- $(e_a$-$e_d)$: vapor pressure curve ($kPa/^oC$)
- $\gamma$: psychrometric constant ($kPa/^oC$)
- 900: conversion factor

6 meteorological stations out of 13 stations (4 BMG stations and 9 stations belonging to Public Works Service of Bali Province) were selected considering the data availability and spatial variation of climate factors, as shown in Table-F.15 and Figure-F.14. ETo calculation requires a set of monthly data, consisting of maximum and minimum temperature, relative humidity, surface wind speed and sunshine hours. Although the data were collected for the last 11 years (1993–2003), the data availability for the most of stations is limited to 9 years at maximum. In fact, Negara (BMG-3), Singaraja (511001) and Tampaksiring (511003) stations have only 5 years data.

**Table-F.15 Meteorological Stations Selected**

| Station No. | Station Name | Data Availability during 1993-2003 | Regency Applied |
|---|---|---|---|
| BMG-1 | Denpasar | - generally 9 year data but 6.5 year for wind speed | Badung, Denpasar |
| BMG-3 | Negara | - 5 year data | Jembrana |
| 511001 | Singaraja | - 5year data | Buleleng |
| 511003 | Tampaksiring | - 4.5 year data | Gianyar, Klungkung, Bangli |
| 511004 | Tiyinggading | - 9 year data | Tabanan |
| 511005 | Susuan | - 9.5 year data | Karangasem |

511001 – 511005 belong to Public Works Service of Bali Province.

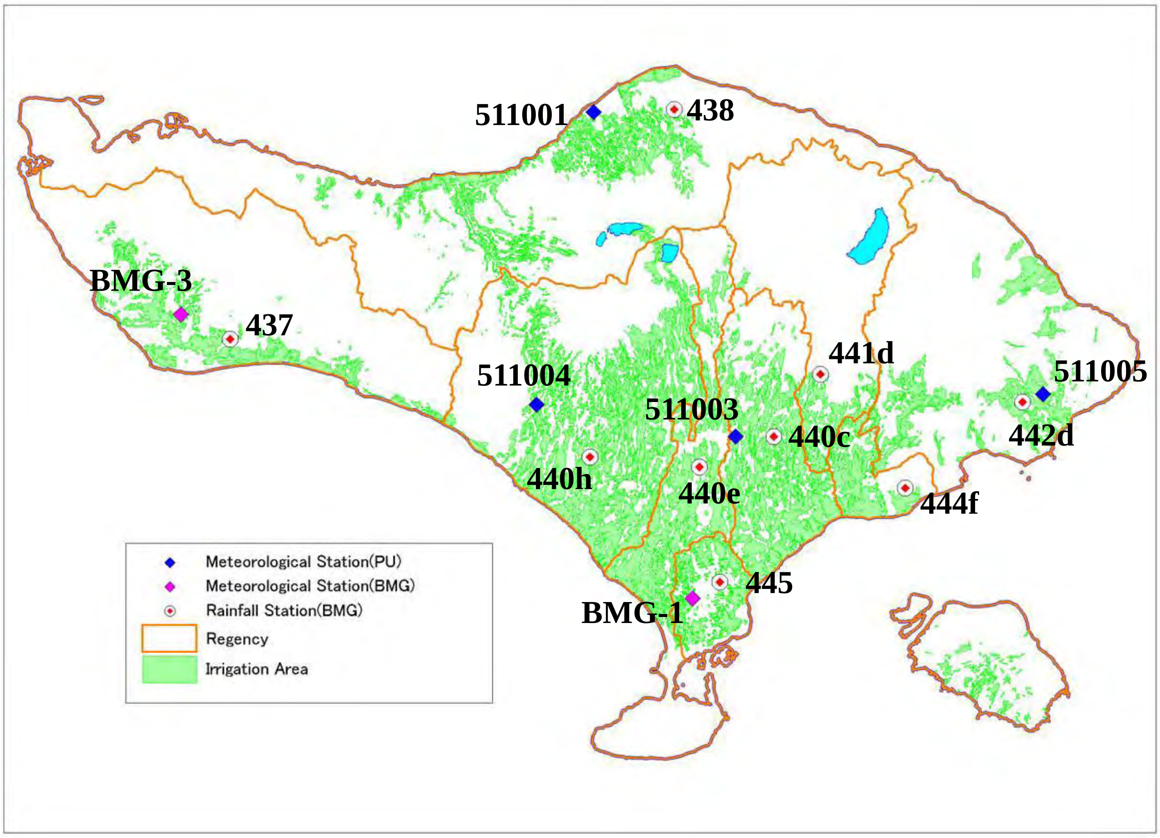
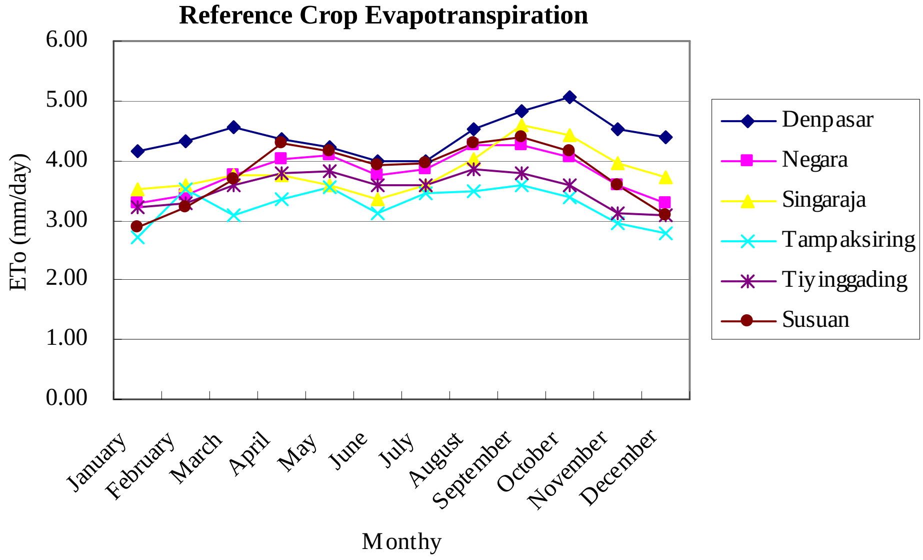



**Figure-F.14 Location Map of Meteorological and Rain Gauge Stations Selected**

Dominant factors controlling evapotranspiration are generally energy to evaporate water (net radiation) and drying power of the air (wind function and slope of saturation vapor pressure, in other words relative humidity). Since relative humidity does not vary much and surface wind velocity is light to moderate throughout the year, the governing factor to fluctuate evapotranspiration seasonally is solar radiation (sunshine hours). As shown in Figure-F.15, ETo has a similar tendency to observed sunshine hours. The fluctuation of observed sunshine hours is explained by Bali's location in the southern hemisphere, which is longer from April to September and shorter from October to March, and clouds coverage in rainy (November – April) and dry season (May – October).

Spatial variation of ETo is also obvious in Figure-F.15. ETo at Denpasar located in the southern Bali Island is higher than that at other stations. ETo at low land tends to be high due to longer sunshine hours and higher temperature. Besides, all data belonging to Public Works Service of Bali Province (DINAS PU) show the low wind velocity compared to BMG data. Most of monthly wind velocities observed by DINAS PU are less than 100 km/day (1.2 m/sec), while BMG stations always shows the monthly wind velocity at the range between 150 km/day (1.7 m/sec) and 250 km/day (3.0 m/sec). Since even 3.0 m/sec is classified moderate wind velocity, this discrepancy depending on agency observed is considered as not a significant effect on ETo calculation. ETo in Bali ranges within 3 mm/day to 5 mm/day.



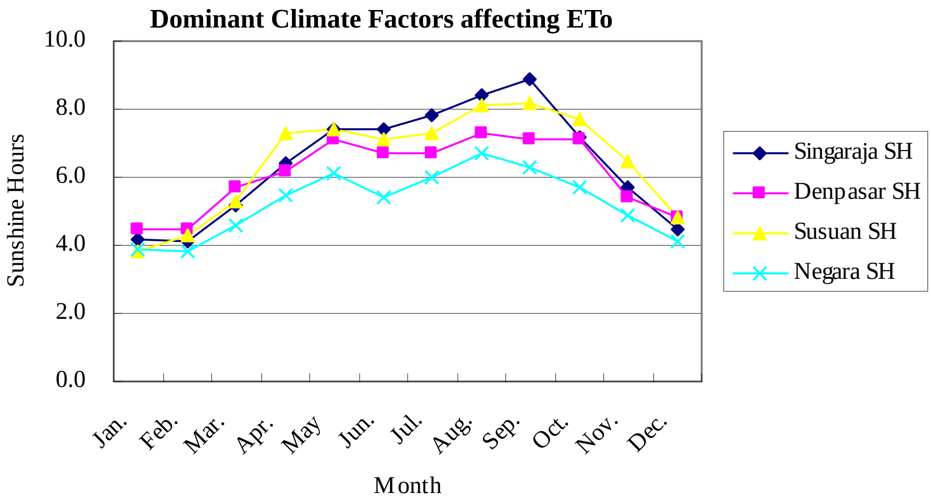




**Figure-F.15 Reference Crop Evapotranspiration**

Crop water requirement of paddy (ETcrop) is calculated by multiplication of reference crop evapotranspiration (ETo) by crop coefficient (kc). Crop coefficient depends on growing stage of crops and kc available in “FAO Irrigation and Drainage Paper 24” is commonly used in Indonesia. Therefore, the kc in Table-F.16 was adopted for paddy culture with the following conditions and assumptions.

- An application of irrigation to *palawija*/vegetables is very limited. Thus, irrigation is considered for paddy only.
- Length of paddy growing season is 110 days after land preparation, adopting the most typical length in Bali.
- Crop water requirement is calculated by 15 days and unit crop area is divided into 2 areas differentiating growing season.
- Starting month of land preparation depends on regency and series of cropping pattern.

**Table-F.16 Crop Coefficient for Paddy**

| Growth Stage | 1st month | | 2nd month | | 3rd month | | 4th month | |
|---|---|---|---|---|---|---|---|---|
| | I | II | I | II | I | II | I | II |
| Crop Coefficient | P | P | 1.10 | 1.10 | 1.05 | 1.05 | 0.95 | |
| | | P | P | 1.10 | 1.10 | 1.05 | 1.05 | 0.95 |
| Average Crop Coefficient | | | 1.10 | 1.10 | 1.08 | 1.05 | 1.00 | 0.95 |

Note: Starting month of paddy culture depends on regency.
P: Land Preparation
The table is an example for 1st paddy.

### F-2.3.2 Effective Rainfall

Effective rainfall (70%$R_{80}$) is rainfall stored in the root zone and effective to the crop growth. Considering annual variation of rainfall, 80 % probability rainfall ($R_{80}$) was adopted as dependable rainfall, and successively 70 % of the dependable rainfall is assumed as the effective rainfall.

As shown in Figure-F.14 and Table-F.17, 9 rain gauge stations were selected considering the data availability and representative station for regency. Available period of monthly rainfall depends on station but a station has at least more than 12 years data. The longest data (36 years) is available at No.440a station (Abiansemal) in Badung.

**Table-F.17 Rain Gauge Stations Selected**

| Station No. | Station Name | Data Availability of Monthly Rainfall | Regency Applied |
|---|---|---|---|
| 437 | Poh Santen | 1972-2001, 30 years | Jembrana |
| 438e | Bengkala | 1983-2001, 19 years | Buleleng |
| 445 | Sumerta | 1990-2001 12 years | Denpasar |
| 440a | Abiansemal | 1967-2002, 36 years | Badung |
| 440c | Tampaksiring | 1984-2001, 18 years | Gianyar |
| 440h | Kerambitan | 1982-2001, 20 years | Tabanan |
| 441d | Susut | 1983-2001, 19 years | Bangli |
| 442d | Bebandem | 1979-2001, 23 years | Karangasem |
| 444f | Dawan | 1985-2001, 17 years | Klungkung |

Figure-F.16 shows 80 % probability rainfall by regency. There is no dependable rainfall in Buleleng during the dry season (May – October), while some dependable rainfall (10 mm/month - 65 mm/month) varying with month is available even during the dry season in Badung, Gianyar, Bangli and Klungkung.

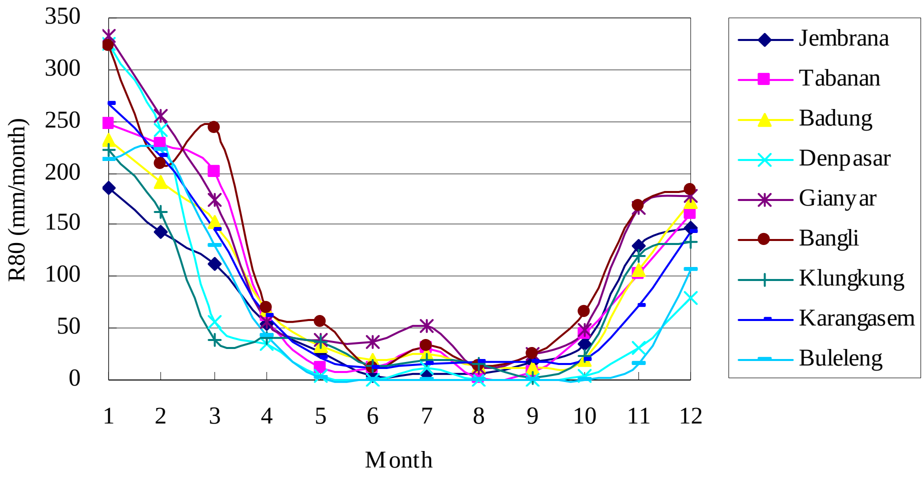



**Figure-F.16 80 % Probability Rainfall (Dependable Rainfall)**

Effective rainfall (70%$R_{80}$) is 70 % of dependable rainfall and the estimate result is summarized in Table-F.18. In accordance with the dependable rainfall, some amount of rainfall (0.3 mm/day – 1.5 mm/day depending on month and location) is available for crop growth even during the dry season contributing to increase in crop intensity of paddy culture.

**Table-F.18 Effective Rainfall**

Unit: mm/day

| Regency | Station | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jembrana | 437 | 4.20 | 3.58 | 2.53 | 1.28 | 0.63 | 0.07 | 0.14 | 0.14 | 0.42 | 0.78 | 3.03 | 3.32 |
| Tabanan | 440h | 5.58 | 5.70 | 4.56 | 1.45 | 0.25 | 0.28 | 0.70 | 0.05 | 0.16 | 0.99 | 2.38 | 3.61 |
| Badung | 440a | 5.24 | 4.78 | 3.43 | 1.56 | 0.75 | 0.44 | 0.59 | 0.29 | 0.26 | 0.43 | 2.46 | 3.91 |
| Denpasar | 445 | 7.34 | 6.05 | 1.29 | 0.79 | 0.07 | 0.00 | 0.25 | 0.00 | 0.00 | 0.09 | 0.72 | 1.81 |
| Gianyar | 440c | 7.50 | 6.38 | 3.92 | 1.33 | 0.86 | 0.84 | 1.20 | 0.27 | 0.61 | 1.11 | 3.90 | 4.00 |
| Bangli | 441d | 7.29 | 5.20 | 5.49 | 1.63 | 1.29 | 0.26 | 0.75 | 0.29 | 0.61 | 1.47 | 3.92 | 4.13 |
| Klungkung | 444f | 5.01 | 4.05 | 3.09 | 0.96 | 0.81 | 0.30 | 0.45 | 0.34 | 0.05 | 0.52 | 2.78 | 3.03 |
| Karangasem | 442d | 6.03 | 5.40 | 3.27 | 1.42 | 0.50 | 0.28 | 0.72 | 0.38 | 0.40 | 0.43 | 1.68 | 3.25 |
| Buleleng | 438e | 4.81 | 5.55 | 2.91 | 1.00 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.37 | 2.42 |

### F-2.3.3 Cropping Pattern and Calendar

As discussed in Chapter 1, cropping pattern and cropping calendar in regency were identified based on “Statistics of Food Crops Agriculture in 2003 (Food Crops Agriculture Service of Bali Province)” and “Report on Cropping Pattern in Paddy Fields in 2003 from 8 regencies and Denpasar”. Since paddy culture dominates irrigation in Bali in terms of area and amount of water consumed, 13 cropping pattern surveyed by regency were integrated into 6 cropping patterns associated with paddy and 1 pattern for other crop cultures/fallow as show in Table-F.19. Table-F.19 is assumed as typical and present cropping pattern and calendar in Bali and was used for projection of irrigation water demand.

## Table-F.19 Cropping Pattern and Calendar

| Cropping | Cropping Calendar | | | | | | | | | | | | Planting Area (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pttern | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Jem | Tab | Bad | Gia | Klu | Ban | Kar | Bul | Den |
| 3 Crops | | | | | | | | | | | | | 1.7 | 27.7 | 46.5 | 30.4 | 8.4 | 39.6 | 4.3 | 29.0 | 8.6 |
| | | | | | | | | | | | | | 11.2 | 7.3 | 38.9 | 7.4 | 43.2 | 36.7 | 33.3 | 38.6 | 27.4 |
| | | | | | | | | | | | | | 8.8 | 0.9 | 0.4 | 2.1 | 33.0 | 7.1 | 46.2 | 9.4 | 17.8 |
| 2 Crops | | | | | | | | | | | | | 17.3 | 54.5 | 9.8 | 47.1 | 2.2 | 12.6 | 4.3 | 8.9 | 15.3 |
| | | | | | | | | | | | | | 35.7 | 2.6 | 0.9 | 2.4 | 6.8 | 4.0 | 5.6 | 13.6 | 16.5 |
| 1 Crop | | | | | | | | | | | | | 20.2 | 5.0 | 2.0 | 6.8 | 6.4 | - | 3.2 | 0.2 | 4.2 |
| Fallow and Other Crops, such as palawija, vegetables; sometime 2 cropping/year | | | | | | | | | | | | | 5.1 | 2.0 | 1.5 | 3.8 | - | - | 3.1 | 0.3 | 10.2 |
| | | | | | | | | | Total (%) | | | | 95 | 98 | 99 | 96 | 100 | 100 | 97 | 100 | 90 |
| | | | | | | | | | Starting Month | | | | Nov | Nov* | Nov | Nov | Nov | Nov | Dec | Dec | Nov |

: paddy (30 days for land preparation & 80 days from transplanting to harvesting)

: palawija/vegetable (90 days)

Note: *: 2 crops and 1 crop also start in November.
Jem: Jembrana, Tab: Tabanan, Bad: Badung, Gia: Gianyar, Klu: Klungkung, Ban: Bangli, Kar: Karangasem, Bul: Buleleng, Den: Denpasar
Source: "Statistics of Food Crops Agriculture in 2003 (Food Crops Agriculture Service of Bali Province)" for Calendar
"Report on Cropping Pattern in Paddy Fields in 2003 from 8 regencies and Denpasar" for Pattern

Triple cropping of paddy is practiced in more than 30 % of regency paddy area in Badung, Gianyar and Bangli, while it is limited to less than 10 % in Jembrana, Klungkung, Karangasem and Denpasar. Double cropping of paddy (2 paddy culture followed by either *palawija* or fallow) contributes to more than 50 % of regency paddy area in Tabanan and Gianyar. These characteristics are consistent with availability of land and water for paddy culture. Wide range of cropping pattern in Denpasar is probably explained by crop diversification. Cropping calendar and pattern of 2003 by regency (Table-F.19) were applied to estimate present and future irrigation water demand.

### F-2.3.4 Other Parameters for Paddy Irrigation

Other parameters required for the estimate of irrigation water demand were set, considering local factors obtained from review of previous studies in Bali, information from agencies concerned and so on. Parameters are summarized below.

#### (1) Irrigation Efficiency

Irrigation efficiency is to take account for losses of water during conveyance, distribution of field canal and field application. According to Public Works Service of Bali Province, 86 % of the potential irrigation area (paddy field equipped with irrigation facilities and the maximum irrigable area) belong to the government project. 40 % and 60 % of the government project are equipped with technical and semi-technical irrigation systems respectively. This is a result of rehabilitation works conducted since 1980s in order to upgrade irrigation system. Thus, most of irrigation schemes in Bali have a conveyance and distribution system with low water loss. Besides, the discharge in canals is regulated in the technical irrigation scheme and there is no significant discontinuance of flow in the most of canals. At the field, *subak* control the field application of water, such as distribution and rotation of water. If high efficiencies were adopted based on these conditions, the overall efficiency would be as follows.

0.9 (Conveyance) x 0.9 (Distribution) x 0.7 (Field Application) = 0.57 (Overall Efficiency)

In general, irrigation efficiency for paddy with a good system (facilities and management) varies from 40–60 % and that of primitive system is less than 40 %. Since 14 % of the potential irrigation area is still considered as primitive system, the overall irrigation efficiencies adopted in this Study is 0.5.

**(2) Percolation/Seepage Loss**

Since the wetland paddy requires maintaining some water depth in the paddy field, there are always percolation losses into soil profiles. Percolation losses vary depending on soil properties, groundwater table, farming method and so on. For the planning and design, percolation losses normally adopted ranges from 1 mm/day for the clayey soil to 5 mm/day for the sandy soil. Considering the following conditions, percolation losses are assumed as 2 mm/day.

- Since paddy culture is intensively conducted with high productivity, it can be assumed that the farming method of paddy is practiced minimizing the percolation losses.
- More than 80 % of the provincial area consists of Latosol and Regosol soils with medium texture. However, the long and continuous cultivation of paddy has improved soil properties in terms of less infiltration.

**(3) Land Preparation and Water Layer Replacement**

Before transplanting paddy seedlings, the large amount of water is required for land preparation, while a water layer is replaced normally twice per one crop season. Based on information from agencies concerned, particularly Food Crops Agriculture Service of Bali Province, an amount of water required for land preparation and water layer replacement is assumed as follows.

- Land preparation requires 200 mm of water and takes 30 days.
- Water layer replacement is conducted one month and two month later after transplanting. Each time, an amount of water necessary is 50 mm and it takes 15 days.

**(4) Conditions and Assumptions**

The following conditions and assumptions were made to estimate the irrigation water demand.

1) Target Crops for Irrigation

As discussed in the previous sections, the paddy culture currently dominates irrigation in Bali. Since almost all irrigable land has been already cultivated for wetland paddy, the further irrigation development targets rehabilitation works to improve the irrigation efficiency in the paddy field, and new irrigation schemes for fruit culture/horticulture with a very limited scale in terms of area and volume of water. The dominance of paddy culture in Bali irrigation will not change by the year of 2025. Therefore, the Study, considers only paddy culture for the present and future irrigation water demand.

2) Unit of Demand Projection

Irrigation water requirement is integrated value of climate factors (ETo and effective rainfall), farming factors (cropping calendar, cropping pattern, land preparation and water layer replacement), soil factors (percolation loss) and water management factors (irrigation efficiency and return flow). Since these factors vary spatially and seasonally, a study at project design requires substantial field observation for soil properties, available discharges, farming and water management practiced. Besides, it needs to conduct a detail study examining local dependable values, such as hydrology, agro-economy and so on.

A project design is a series of studies at different level from wide rage to specific goals/sites. Since the Study is at a master plan level to examine conditions, issues and countermeasures for the whole Bali Province, an effective and efficient way of the study is to deal with subjects by approximation and average over some certain area. The complexity of irrigation system in Bali has led lots of unknown factors, such as area and location of irrigation schemes, water conveyance and distribution system, volume of return flow and so on. Therefore, factors associated with irrigation were identified and examined by regency and irrigation water demand projection was also conducted by regency as the minimum unit.

3) Projection of Future Paddy Area

One of the important policies stipulated in the spatial plan and RENSTRA is to protect the paddy field from change in function. RENSTRA specify the concrete target to mitigate a present decrease in the paddy area, from 1.01 % to 0.45 % in provincial average during 2004 - 2008. However, it is not realistic that the RENSTRA policy works immediately since 2004, considering the continuous decrease in the last 7 years (1997 – 2003). Through the discussion with government agencies concerned, particularly Public Works Service of Bali Province and Food Crops Agriculture Service of Bali Province, and analysis of factors affecting decline tendency of paddy area, the following rates of decrease are considered reasonable and adopted in this Study.

| Period | Provincial Average of Decreasing Rates |
|---|---|
| 2003 – 2005: | transition period from 1.01 % to 0.45 % (RENSTRA target) |
| 2005 – 2015: | decreasing rate of 0.45 % |
| 2015 – 2025: | decreasing rate of 0.24 % |

**Table-F.20 Projection of Wetland Paddy Area by Regency**

| Regency | Area of Paddy Field (ha) | | | | | | Average Decreasing Ratio (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2003 | 2005 | 2010 | 2015 | 2020 | 2025 | 2003-2005 | 2005-2015 | 2015-2025 | 2003-2025 |
| Jembrana | 7,013 | 6,675 | 6,278 | 5,965 | 5,785 | 5,611 | -2.44 | -1.12 | -0.61 | -1.01 |
| Tabanan | 22,639 | 22,251 | 21,777 | 21,390 | 21,161 | 20,935 | -0.86 | -0.39 | -0.21 | -0.36 |
| Badung | 10,334 | 9,949 | 9,490 | 9,124 | 8,912 | 8,704 | -1.88 | -0.86 | -0.47 | -0.78 |
| Gianyar | 14,937 | 14,812 | 14,657 | 14,529 | 14,453 | 14,377 | -0.42 | -0.19 | -0.11 | -0.17 |
| Klungkung | 3,932 | 3,894 | 3,847 | 3,808 | 3,785 | 3,762 | -0.48 | -0.22 | -0.12 | -0.20 |
| Bangli | 2,888 | 2,888 | 2,888 | 2,888 | 2,888 | 2,888 | 0.00 | 0.00 | 0.00 | 0.00 |
| Karangasem | 7,034 | 6,946 | 6,837 | 6,748 | 6,695 | 6,642 | -0.63 | -0.29 | -0.16 | -0.26 |
| Buleleng | 11,011 | 10,877 | 10,712 | 10,577 | 10,497 | 10,417 | -0.61 | -0.28 | -0.15 | -0.25 |
| Denpasar | 2,856 | 2,718 | 2,556 | 2,428 | 2,355 | 2,283 | -2.45 | -1.12 | -0.61 | -1.01 |
| Total | 82,644 | 81,010 | 79,042 | 77,457 | 76,531 | 75,619 | -0.99 | -0.45 | -0.24 | -0.40 |

Source: Food Crops Agriculture Service of Bali Province for area in 2003
Estimation of JICA Study Team for the projected area

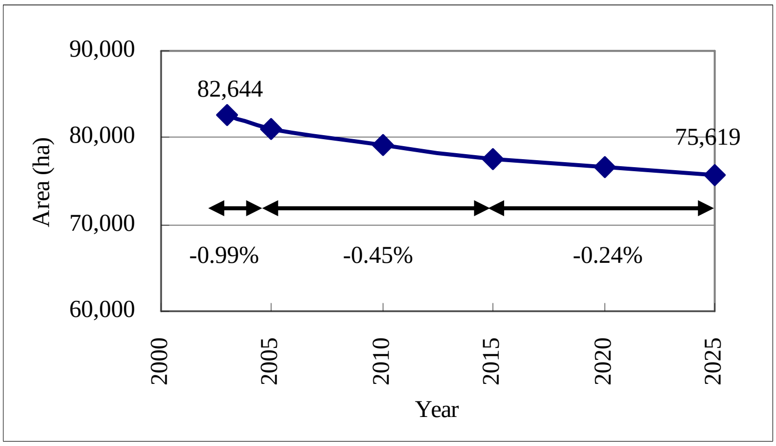



**Figure-F.17 Projection of Provincial Paddy Area**

4) New Irrigation Development

As discussed in Chapter 1, almost all arable land for paddy is already cultivated intensively in Bali. Based on the present conditions and the agriculture development plans (the spatial plan and RENSTRA), it is assumed that there is no significant extension of new irrigation project due to the following reasons. Thus, the present situation that dominant crop of Bali irrigation is wetland paddy will not change.

- Considering the availability of water, surface water development for irrigation requires a storage facility, such as dams. If the storage facility targets only irrigation, it will not be feasible in terms of cost vs. benefit. Therefore, surface water development will not be applied just for new irrigation schemes. However, if the surface water development targets the multiple functions, including irrigation, it might be feasible contributing to increase in crop intensity.

- There are some new irrigation schemes for fruit culture and horticulture by groundwater development but its scale is very small. These schemes will be promoted but their scale will be negligibly small in terms of area and water consumption.

5) Cropping Pattern and Calendar

With the following reasons, the present cropping pattern and calendar in the paddy fields are assumed not to alter and applied to the future projection of irrigation water demand.

- Paddy/*palawija* culture will be maintained in accordance with the provincial policy of self sufficiency of food crops. Therefore, the market oriented crop diversification will mainly happen in the dry land.
- Since the double cropping of paddy followed by *palawija*/fallow is ideal considering maintaining soil fertility and disease control, the triple cropping of paddy will not extend from the present area.

## F-2.4 Irrigation Plan

Based on the present conditions of irrigation system and agriculture development plans (the spatial plan and *RENSTRA*), the strategy for future irrigation and irrigation plans with alternatives were formulated.

### F-2.4.1 Issues Associated with Present Irrigation System

Although the paddy culture in Bali has already achieved high crop intensity and high productivity with intensive and extensive irrigation, there are still some issues as summarized below. These issues need to be mitigated for the future irrigation.

- **Irrigation Efficiency:** The excess use of water resources should be mitigated by improving the irrigation efficiency so that the residual water can be utilized to increase productivity/production of crops. 14 % of irrigation area (paddy field) equipped with primitive irrigation facilities are the first priority for an improvement of irrigation efficiency.
- **Volume Control of Intake Discharge:** Technical irrigation schemes, which measure and regulate the intake discharge, cover only 32 % of the irrigation area in Bali. Therefore, the volume of water cannot be controlled in the rest of irrigation schemes, 68 % of the irrigation area. Considering effective and efficient water use, the irrigation schemes require to be upgraded to the technical irrigation system so as to control the volume of water, particularly the irrigation system in Tabanan Regency, where the technical irrigation system is rare despite its superiority of paddy irrigation.
- **Unit of Irrigation Water:** *Subak* uses the flow area (*tektek*) for allocation and distribution of water, instead of discharge. This unit of irrigation water makes hard to optimize the water use with other sectors and introduce the concept of water right. As the water balance between demand and supply is already tight, particularly in urban areas, a common sense to measure water by discharge needs to be understood by *Subak* with detailed technical assessment of exact irrigation water requirement and promotion through public consultation meetings.
- **Irrigation Management:** *Subak* is a model of the water users association in terms of O/M of irrigation facilities and water allocation. However, the optimization of water use among all water sectors requires more precise volume control of water because the tight water balance between demand and supply is anticipated. For the precise volume control, it is necessary to identify the location and area of irrigation schemes with a network from intake to drainage, discharges from an intake to field inlets, volumes of drained water/return flow and so on. However, the availability of those data is very limited. Public Works Service of Bali Province is recently conducting a study for identification of irrigation schemes by regency. This study is expected to cover the whole Bali Province and target to identify the above factors in details.
- **Decrease in Paddy Field:** The recent decreasing tendency of paddy field needs to

be mitigated and controlled because the paddy field benefits not only self-sufficiency of staple food (paddy) but also many factors, such as flood control, groundwater recharge, stabilization of river flow, water quality control, eco-system and tourism. Besides, the paddy culture is associated with tradition and religion through *Subak*. Thus, the rapid decrease in the paddy field will affect the Balinese culture and tradition.

### F-2.4.2 Strategy for Future Irrigation

Based on the two agricultural plans (the spatial plan and *RENSTRA*) and present issues regarding irrigation, the following is the strategy for the future irrigation development in Bali.

1) Considering the importance of paddy in Bali, the decreasing tendency of paddy field needs to be mitigated and the mitigation will probably follow the rates below.

| Period | Provincial Average of Decreasing Rates |
|---|---|
| 2003 – 2005: | transition period from 1.01 % to 0.45 % (RENSTRA target) |
| 2005 – 2015: | decreasing rate of 0.45 % |
| 2015 – 2025: | decreasing rate of 0.24 % |

2) The large surface water development, such as dam, will not be applied just for irrigation schemes because of rare feasibility in terms of cost vs. benefit. However, if the surface water development targets the multiple functions, including irrigation, it might be economically feasible and will contribute to increase in crop intensity.
3) The potential area for a new irrigation scheme is very limited in terms of availability of arable land and water resources. Thus, new irrigation schemes for fruit culture and horticulture by groundwater development will be promoted but at limited scale in terms of area and volume of water consumed.
4) Crop diversification will progress and selection of crop culture will be market oriented. Since the crop diversification will extend in the dry land and paddy field during the dry season by the rain-fed culture, the significance of paddy culture with irrigation will be maintained.
5) Potential arable dry land will be utilized for *palawija*/horticulture/fruit culture but application of irrigation will be limited.
6) Rehabilitation works of irrigation facilities will be applied continuously to improve irrigation efficiency, resulting in mitigation of water loss, improvement of crop intensity and improvement of O/M of irrigation facilities. The target to improve irrigation efficiency for wetland paddy is from 50% (present) to 60%.

### F-2.4.3 Irrigate Plans with Alternatives

The basic plan is based on the above strategy, excluding the effect of rehabilitation works on improvement of irrigation efficiency. Since the rehabilitation works target the improvement of irrigation efficiency, they will benefit to mitigate water loss. As a result, the saved water can be used to increase in crop intensity. Besides, the significance of wetland paddy irrigation will not alter in accordance with agriculture development plans (the spatial plan and *RENSTRA*). Therefore, alternative irrigation plans were formulated, considering improvement of irrigation efficiency and increase in crop intensity of paddy by the saved water.

As shown in Table-F.21, there are two alternatives as long as paddy irrigation is considered. One (Alternative 1) is to use the residual water without storage facilities. As a result, the available water to increase the crop intensity of paddy is limited to a certain crop season and the residual water in the rest of season drains to the downstream. Another (Alternative 2) is to use the residual water with storage facilities so that the residual water in the whole year can be utilized.

**Table-F.21 Alternative Irrigation Plans**

| Plans | Basic Plan | Alternative 1 | Alternative 2 |
|---|---|---|---|
| Difference from Present Conditions (Strategy) | • Area decrease in wetland paddy is mitigated in accordance with the projection set by the Bali Province. | • Area decrease in wetland paddy is mitigated in accordance with the projection set by the Bali Province.<br>• Irrigation Efficiency will be improved from 50% to 60% by 2025.<br>• Residual water will be used to increase crop intensity of paddy (2 paddy cropping/year). | • Area decrease in wetland paddy is mitigated in accordance with the projection set by the Bali Province.<br>• Irrigation Efficiency will be improved from 50% to 60% by 2025.<br>• Residual water will be used to increase crop intensity of paddy (2 paddy cropping/year).<br>• There will be surface water development to store the residual water throughout the year. |

## F-2.5 Irrigation Water Demand

### F-2.5.1 Irrigation Water Demand with Basic Plan

#### (1) Irrigation Water Demand per Unit Area

Irrigation water demand was estimated with conditions and assumptions described in the section above. However, strategy applied for the basic plan excludes the effect by irrigation efficiency improvement. Thus, the irritation efficiency is constant at 50%.

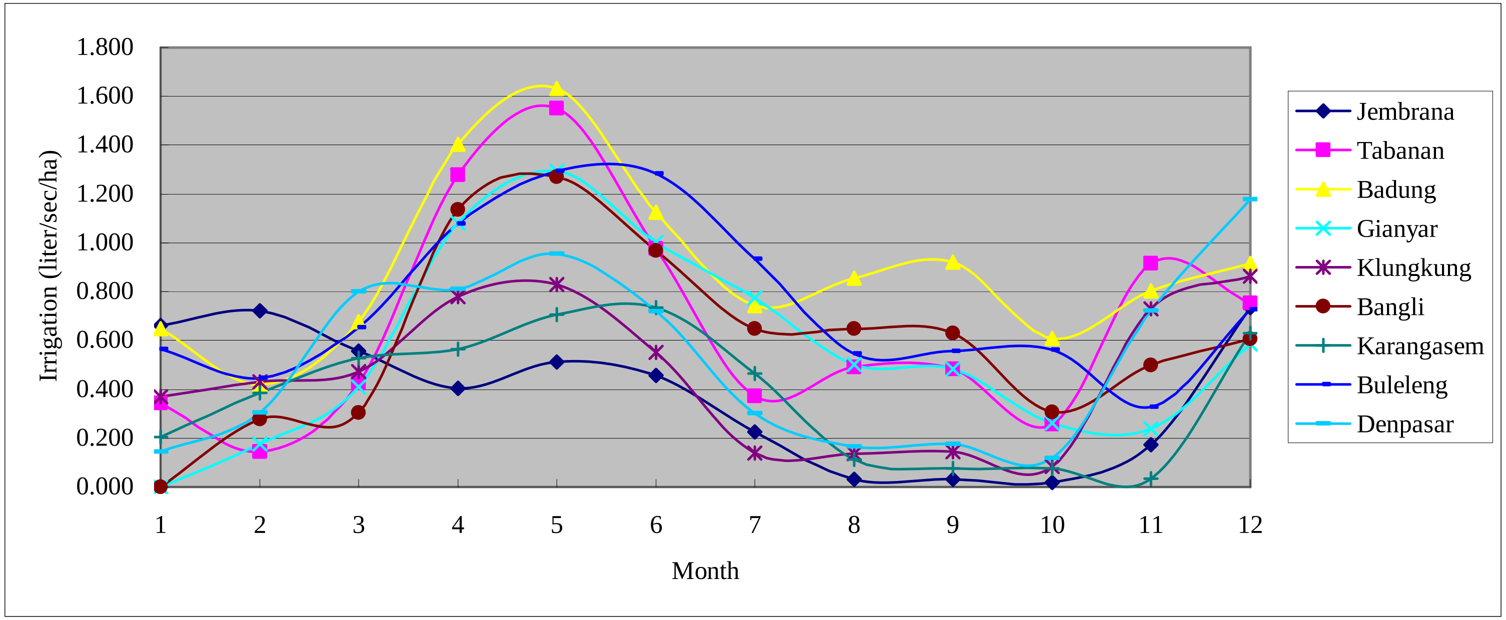
Table-F.22 summarizes the irrigation water requirement (intake volume) estimated and those figures are assumed to reflect the present consumption of irrigation water. High crop intensity of paddy and low effective rainfall during the dry season induce high irrigation water demand in May and September. As cropping pattern and intensities are based on the data in 2003, the figure implies that there is some available river discharge to sustain such demand.

## Table-F.22 Irrigation Water Requirement per Unit Area

Unit: liter/sec/ha

| No. | Regency | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | Jembrana | 0.660 | 0.722 | 0.557 | 0.405 | 0.511 | 0.456 | 0.226 | 0.031 | 0.031 | 0.018 | 0.174 | 0.734 |
| 02 | Tabanan | 0.345 | 0.146 | 0.426 | 1.278 | 1.552 | 0.976 | 0.373 | 0.490 | 0.484 | 0.257 | 0.917 | 0.753 |
| 03 | Badung | 0.647 | 0.421 | 0.678 | 1.405 | 1.632 | 1.125 | 0.743 | 0.855 | 0.920 | 0.608 | 0.802 | 0.915 |
| 04 | Gianyar | 0.000 | 0.175 | 0.411 | 1.082 | 1.295 | 1.002 | 0.775 | 0.500 | 0.484 | 0.262 | 0.240 | 0.585 |
| 05 | Klungkung | 0.370 | 0.430 | 0.473 | 0.780 | 0.829 | 0.552 | 0.140 | 0.137 | 0.145 | 0.084 | 0.729 | 0.863 |
| 06 | Bangli | 0.000 | 0.278 | 0.305 | 1.136 | 1.270 | 0.969 | 0.648 | 0.649 | 0.630 | 0.308 | 0.498 | 0.607 |
| 07 | Karangasem | 0.204 | 0.386 | 0.528 | 0.565 | 0.707 | 0.734 | 0.466 | 0.112 | 0.077 | 0.077 | 0.033 | 0.631 |
| 08 | Buleleng | 0.565 | 0.445 | 0.655 | 1.078 | 1.293 | 1.283 | 0.933 | 0.546 | 0.556 | 0.563 | 0.329 | 0.728 |
| 71 | Denpasar | 0.144 | 0.304 | 0.801 | 0.811 | 0.956 | 0.720 | 0.303 | 0.164 | 0.176 | 0.119 | 0.721 | 1.178 |

Irrigation Efficiency = 50%



**(2) Present and Future Irrigation Water Demand**

Present and future irrigation water demand is a multiplication of the irrigation water requirement per unit area by the area of paddy field. Since climate factors, farming factors and water management factors are assumed not to vary, the irrigation water requirement per unit area estimated for the year of 2003 is applicable to the future irrigation water demand. Thus, the change in paddy area is only a factor affecting the future irrigation water demand.

Table-F.23 summarizes the irrigation water demand by regency, while Table-F.24 shows the monthly fluctuation of irrigation water demand. A decline in irrigation water is due to the area decrease of paddy field. The provincial irrigation water demand will decrease from 1,625 million $m^3$ in 2003 to 1,485 million $m^3$ in 2025. Since the decreasing rates of regency vary depending on local conditions, such as decreasing rates in paddy area, crop intensity of paddy and so on, the residual water of regency (difference between water demands in 2003 and in 2025) ranges from 0 to 46 million $m^3$.

**Table-F.23 Irrigation Water Demand by Regency**

Unit: million $m^3$

| No. | Regency | Year | | | | | | Difference |
|---|---|---|---|---|---|---|---|---|
| | | 2003 | 2005 | 2010 | 2015 | 2020 | 2025 | 2025-2003 |
| 01 | Jembrana | 82.97 | 78.99 | 74.23 | 70.60 | 68.47 | 66.37 | -16.60 |
| 02 | Tabanan | 476.69 | 468.59 | 458.58 | 450.46 | 445.55 | 440.83 | -35.86 |
| 03 | Badung | 292.61 | 281.68 | 268.70 | 258.29 | 252.36 | 246.41 | -46.20 |
| 04 | Gianyar | 268.07 | 265.80 | 263.02 | 260.72 | 259.38 | 258.03 | -10.04 |
| 05 | Klungkung | 57.03 | 56.51 | 55.81 | 55.22 | 54.94 | 54.59 | -2.44 |
| 06 | Bangli | 55.43 | 55.43 | 55.43 | 55.43 | 55.43 | 55.43 | 0.00 |
| 07 | Karangasem | 83.50 | 82.42 | 81.23 | 80.13 | 79.51 | 78.82 | -4.68 |
| 08 | Buleleng | 260.23 | 257.03 | 253.12 | 249.95 | 248.04 | 246.18 | -14.05 |
| 71 | Denpasar | 48.10 | 45.79 | 43.03 | 40.93 | 39.65 | 38.39 | -9.71 |
| Total | | 1,624.63 | 1,592.24 | 1,553.15 | 1,521.73 | 1,503.33 | 1,485.05 | -139.58 |

Irrigation Efficiency = 50%
Source: Estimate of JICA Study Team

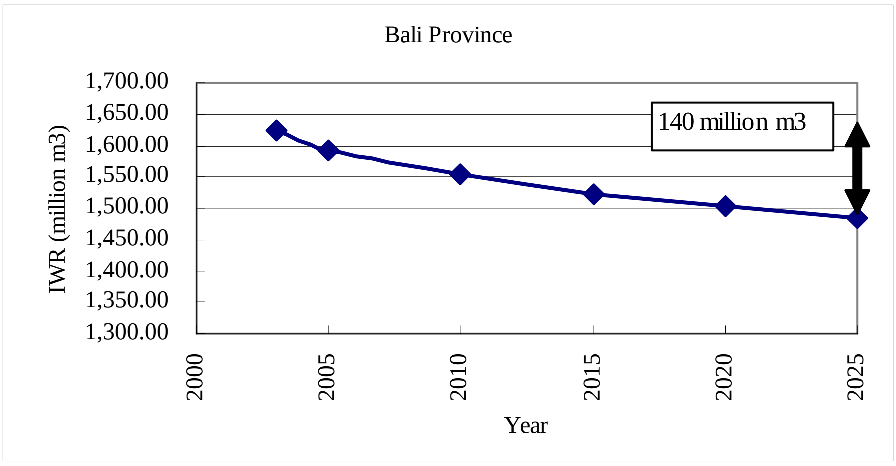



**Figure-F.18 Decrease in Irrigation Water Demand**

## Table-F.24 (1/2) Irrigation Water Demand

Unit million m$^3$

| | No. | Regency | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 01 | Jembrana | 12.40 | 12.24 | 10.45 | 7.36 | 9.59 | 8.27 | 4.23 | 0.59 | 0.54 | 0.35 | 3.16 | 13.79 | 82.97 | 1,624.63 |
| | 02 | Tabanan | 20.92 | 7.96 | 25.82 | 74.99 | 94.07 | 57.23 | 22.58 | 29.70 | 28.38 | 15.56 | 53.81 | 45.67 | 476.69 | |
| | 03 | Badung | 17.92 | 10.52 | 18.75 | 37.64 | 45.18 | 30.14 | 20.54 | 23.65 | 24.65 | 16.82 | 21.49 | 25.31 | 292.61 | |
| | 04 | Gianyar | 0.00 | 6.31 | 16.42 | 41.86 | 51.80 | 38.78 | 31.02 | 20.01 | 18.71 | 10.47 | 9.28 | 23.41 | 268.07 | |
| | 05 | Klungkung | 3.88 | 4.09 | 4.98 | 7.96 | 8.73 | 5.62 | 1.47 | 1.45 | 1.48 | 0.88 | 7.41 | 9.08 | 57.03 | |
| | 06 | Bangli | 0.00 | 1.94 | 2.36 | 8.50 | 9.83 | 7.26 | 5.01 | 5.01 | 4.72 | 2.38 | 3.73 | 4.69 | 55.43 | |
| | 07 | Karangasem | 3.83 | 6.56 | 9.94 | 10.29 | 13.31 | 13.37 | 8.76 | 2.12 | 1.40 | 1.45 | 0.60 | 11.87 | 83.50 | |
| | 08 | Buleleng | 16.66 | 11.85 | 19.31 | 30.74 | 38.14 | 36.62 | 27.51 | 16.10 | 15.86 | 16.58 | 9.38 | 21.48 | 260.23 | |
| | 71 | Denpasar | 1.10 | 2.10 | 6.13 | 6.01 | 7.31 | 5.31 | 2.33 | 1.26 | 1.30 | 0.91 | 5.34 | 9.00 | 48.10 | |
| 2005 | 01 | Jembrana | 11.81 | 11.66 | 9.94 | 7.00 | 9.13 | 7.88 | 4.04 | 0.56 | 0.52 | 0.32 | 3.01 | 13.12 | 78.99 | 1,592.24 |
| | 02 | Tabanan | 20.57 | 7.84 | 25.39 | 73.72 | 92.46 | 56.27 | 22.20 | 29.19 | 27.89 | 15.29 | 52.88 | 44.89 | 468.59 | |
| | 03 | Badung | 17.25 | 10.11 | 18.05 | 36.24 | 43.50 | 29.00 | 19.79 | 22.77 | 23.72 | 16.20 | 20.68 | 24.37 | 281.68 | |
| | 04 | Gianyar | 0.00 | 6.27 | 16.28 | 41.52 | 51.34 | 38.44 | 30.75 | 19.85 | 18.56 | 10.37 | 9.20 | 23.22 | 265.80 | |
| | 05 | Klungkung | 3.86 | 4.04 | 4.93 | 7.88 | 8.65 | 5.57 | 1.47 | 1.42 | 1.45 | 0.88 | 7.36 | 9.00 | 56.51 | |
| | 06 | Bangli | 0.00 | 1.94 | 2.36 | 8.50 | 9.83 | 7.26 | 5.01 | 5.01 | 4.72 | 2.38 | 3.73 | 4.69 | 55.43 | |
| | 07 | Karangasem | 3.78 | 6.48 | 9.80 | 10.16 | 13.15 | 13.19 | 8.65 | 2.09 | 1.37 | 1.42 | 0.60 | 11.73 | 82.42 | |
| | 08 | Buleleng | 16.45 | 11.71 | 19.07 | 30.38 | 37.66 | 36.18 | 27.19 | 15.88 | 15.66 | 16.39 | 9.25 | 21.21 | 257.03 | |
| | 71 | Denpasar | 1.04 | 2.01 | 5.84 | 5.70 | 6.96 | 5.08 | 2.20 | 1.21 | 1.24 | 0.86 | 5.08 | 8.57 | 45.79 | |
| 2010 | 01 | Jembrana | 11.09 | 10.96 | 9.35 | 6.58 | 8.57 | 7.41 | 3.80 | 0.51 | 0.49 | 0.29 | 2.83 | 12.35 | 74.23 | 1,553.15 |
| | 02 | Tabanan | 20.11 | 7.67 | 24.86 | 72.14 | 90.50 | 55.05 | 21.72 | 28.58 | 27.29 | 14.97 | 51.76 | 43.93 | 458.58 | |
| | 03 | Badung | 16.45 | 9.65 | 17.22 | 34.55 | 41.49 | 27.68 | 18.88 | 21.72 | 22.63 | 15.45 | 19.73 | 23.25 | 268.70 | |
| | 04 | Gianyar | 0.00 | 6.19 | 16.12 | 41.08 | 50.81 | 38.05 | 30.43 | 19.63 | 18.38 | 10.26 | 9.12 | 22.95 | 263.02 | |
| | 05 | Klungkung | 3.80 | 3.99 | 4.87 | 7.78 | 8.54 | 5.50 | 1.45 | 1.42 | 1.45 | 0.86 | 7.26 | 8.89 | 55.81 | |
| | 06 | Bangli | 0.00 | 1.94 | 2.36 | 8.50 | 9.83 | 7.26 | 5.01 | 5.01 | 4.72 | 2.38 | 3.73 | 4.69 | 55.43 | |
| | 07 | Karangasem | 3.72 | 6.39 | 9.67 | 10.01 | 12.94 | 12.99 | 8.52 | 2.06 | 1.37 | 1.42 | 0.60 | 11.54 | 81.23 | |
| | 08 | Buleleng | 16.20 | 11.54 | 18.78 | 29.91 | 37.10 | 35.61 | 26.76 | 15.64 | 15.42 | 16.15 | 9.12 | 20.89 | 253.12 | |
| | 71 | Denpasar | 0.99 | 1.89 | 5.49 | 5.37 | 6.54 | 4.77 | 2.06 | 1.12 | 1.17 | 0.80 | 4.77 | 8.06 | 43.03 | |

## Table-F.24 (2/2) Irrigation Water Demand

Unit: million $m^3$

| | No. | Regency | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | 01 | Jembrana | 10.55 | 10.43 | 8.89 | 6.25 | 8.17 | 7.05 | 3.62 | 0.48 | 0.47 | 0.29 | 2.67 | 11.73 | 70.60 | 1,521.73 |
| | 02 | Tabanan | 19.77 | 7.52 | 24.40 | 70.87 | 88.90 | 54.10 | 21.35 | 28.07 | 26.80 | 14.70 | 50.83 | 43.15 | 450.46 | |
| | 03 | Badung | 15.80 | 9.29 | 16.55 | 33.23 | 39.88 | 26.59 | 18.13 | 20.89 | 21.75 | 14.87 | 18.97 | 22.34 | 258.29 | |
| | 04 | Gianyar | 0.00 | 6.14 | 15.96 | 40.72 | 50.38 | 37.71 | 30.16 | 19.45 | 18.20 | 10.18 | 9.05 | 22.77 | 260.72 | |
| | 05 | Klungkung | 3.78 | 3.97 | 4.82 | 7.70 | 8.44 | 5.44 | 1.42 | 1.39 | 1.43 | 0.86 | 7.18 | 8.79 | 55.22 | |
| | 06 | Bangli | 0.00 | 1.94 | 2.36 | 8.50 | 9.83 | 7.26 | 5.01 | 5.01 | 4.72 | 2.38 | 3.73 | 4.69 | 55.43 | |
| | 07 | Karangasem | 3.67 | 6.29 | 9.54 | 9.88 | 12.78 | 12.83 | 8.41 | 2.04 | 1.35 | 1.39 | 0.57 | 11.38 | 80.13 | |
| | 08 | Buleleng | 15.99 | 11.39 | 18.53 | 29.55 | 36.64 | 35.17 | 26.44 | 15.45 | 15.24 | 15.94 | 8.99 | 20.62 | 249.95 | |
| | 71 | Denpasar | 0.94 | 1.79 | 5.20 | 5.11 | 6.21 | 4.54 | 1.98 | 1.07 | 1.11 | 0.78 | 4.54 | 7.66 | 40.93 | |
| 2020 | 01 | Jembrana | 10.23 | 10.11 | 8.62 | 6.07 | 7.90 | 6.84 | 3.51 | 0.48 | 0.47 | 0.27 | 2.59 | 11.38 | 68.47 | 1,503.33 |
| | 02 | Tabanan | 19.55 | 7.45 | 24.13 | 70.09 | 87.93 | 53.50 | 21.11 | 27.78 | 26.52 | 14.54 | 50.28 | 42.67 | 445.55 | |
| | 03 | Badung | 15.45 | 9.07 | 16.18 | 32.45 | 38.94 | 26.00 | 17.73 | 20.41 | 21.25 | 14.52 | 18.53 | 21.83 | 252.36 | |
| | 04 | Gianyar | 0.00 | 6.12 | 15.88 | 40.51 | 50.11 | 37.51 | 30.00 | 19.36 | 18.12 | 10.12 | 8.99 | 22.66 | 259.38 | |
| | 05 | Klungkung | 3.75 | 3.94 | 4.79 | 7.65 | 8.41 | 5.42 | 1.42 | 1.39 | 1.43 | 0.86 | 7.15 | 8.73 | 54.94 | |
| | 06 | Bangli | 0.00 | 1.94 | 2.36 | 8.50 | 9.83 | 7.26 | 5.01 | 5.01 | 4.72 | 2.38 | 3.73 | 4.69 | 55.43 | |
| | 07 | Karangasem | 3.64 | 6.24 | 9.45 | 9.80 | 12.67 | 12.73 | 8.36 | 2.01 | 1.35 | 1.39 | 0.57 | 11.30 | 79.51 | |
| | 08 | Buleleng | 15.88 | 11.30 | 18.40 | 29.32 | 36.35 | 34.91 | 26.22 | 15.35 | 15.11 | 15.80 | 8.94 | 20.46 | 248.04 | |
| | 71 | Denpasar | 0.91 | 1.74 | 5.06 | 4.95 | 6.03 | 4.38 | 1.90 | 1.04 | 1.06 | 0.75 | 4.41 | 7.42 | 39.65 | |
| 2025 | 01 | Jembrana | 9.91 | 9.80 | 8.36 | 5.88 | 7.66 | 6.64 | 3.40 | 0.46 | 0.44 | 0.27 | 2.51 | 11.04 | 66.37 | 1,485.05 |
| | 02 | Tabanan | 19.34 | 7.38 | 23.89 | 69.34 | 86.99 | 52.93 | 20.89 | 27.48 | 26.23 | 14.38 | 49.77 | 42.21 | 440.83 | |
| | 03 | Badung | 15.08 | 8.85 | 15.80 | 31.70 | 38.03 | 25.38 | 17.30 | 19.93 | 20.76 | 14.17 | 18.09 | 21.32 | 246.41 | |
| | 04 | Gianyar | 0.00 | 6.10 | 15.80 | 40.31 | 49.85 | 37.32 | 29.84 | 19.26 | 18.01 | 10.07 | 8.94 | 22.53 | 258.03 | |
| | 05 | Klungkung | 3.72 | 3.92 | 4.77 | 7.59 | 8.36 | 5.37 | 1.42 | 1.37 | 1.43 | 0.86 | 7.10 | 8.68 | 54.59 | |
| | 06 | Bangli | 0.00 | 1.94 | 2.36 | 8.50 | 9.83 | 7.26 | 5.01 | 5.01 | 4.72 | 2.38 | 3.73 | 4.69 | 55.43 | |
| | 07 | Karangasem | 3.62 | 6.19 | 9.37 | 9.72 | 12.56 | 12.62 | 8.28 | 1.98 | 1.32 | 1.37 | 0.57 | 11.22 | 78.82 | |
| | 08 | Buleleng | 15.75 | 11.23 | 18.27 | 29.08 | 36.08 | 34.66 | 26.03 | 15.21 | 15.01 | 15.70 | 8.86 | 20.30 | 246.18 | |
| | 71 | Denpasar | 0.88 | 1.67 | 4.90 | 4.80 | 5.84 | 4.25 | 1.85 | 0.99 | 1.04 | 0.72 | 4.25 | 7.20 | 38.39 | |

### F-2.5.2 Evaluation of Alternative Irrigation Plans

The irrigation water demands with the Alternative 1 and Alternative 2 plans were estimated by changing the irrigation efficiency in the basic plan. Assuming that 60% irrigation efficiency covers the whole irrigation area by the year of 2025, the comparison of irrigation water demands among the basic and alternative plans was made for the demand in only 2025. As shown in Table-F.25, the residual water in the year of 2025 amounts to approximately 387 million $m^3$ because of improvement in irrigation efficiency and area decrease in paddy field. Improvement in irrigation efficiency and area decrease in paddy field contribute to 247 million $m^3$ and 140 million $m^3$ reduction of irrigation water respectively. Besides, 10% increase in irrigation efficiency (from 50% to 60%) save 17% of water compared to the irrigation water requirement in 2025 with 50% efficiency.

With this residual water, the crop intensity of paddy will be improved from one paddy cropping to two paddy cropping followed by other crops (*palawija*/vegetables). Although the cropping pattern is a function of not only available water but also other factors such as soil properties, topographic characteristics, agro-business and so on, an improvement of crop intensity was examined in terms of water resources because a main concern of the Study is the water resources development. Assumptions and conditions made for assessment of residual water effect on increase in crop intensity of paddy are as follows.

- An increase in crop intensity considers only paddy because maximization of paddy production is the government policy and paddy culture dominates irrigation in Bali.
- Two paddy cropping followed by *palawija*/vegetables is the target cropping pattern by using the residual water. As a result, the crop intensity including paddy and other crops will be 300%.
- Irrigation is not applied to *palawija*/vegetables.

**Table-F.25 Effect of Irrigation Efficiency Improvement & Paddy Area Decrease**

Unit: million $m^3$

| No. | Regency | Residual Water by Paddy Area Decrease = Q2003 – Q2025 | Irrigation Water Demand in 2025 | | Residual Water by IEI = 1) – 2) |
|---|---|---|---|---|---|
| | | | 1) 50% Irrigation Efficiency | 2) 60% Irrigation Efficiency | |
| 01 | Jembrana | 16.60 | 66.37 | 55.31 | 11.06 |
| 02 | Tabanan | 35.86 | 440.83 | 367.44 | 73.39 |
| 03 | Badung | 46.20 | 246.41 | 205.37 | 41.04 |
| 04 | Gianyar | 10.04 | 258.03 | 215.08 | 42.95 |
| 05 | Klungkung | 2.44 | 54.59 | 45.45 | 9.14 |
| 06 | Bangli | 0.00 | 55.43 | 46.17 | 9.26 |
| 07 | Karangasem | 4.68 | 78.82 | 65.78 | 13.04 |
| 08 | Buleleng | 14.05 | 246.18 | 205.07 | 41.11 |
| 71 | Denpasar | 9.71 | 38.39 | 32.04 | 6.35 |
| Total | | 139.58 | 1,485.05 | 1,237.71 | 247.34 |

Q2003: Irrigation Water Demand in 2003, Q2025: Irrigation Water Demand in 2025
IEI: Irrigation Efficiency Improvement

The target area of crop intensity improvement for paddy is the area where only one paddy cropping is practiced followed by fallow or other crops, such as *palawija* and vegetables. The target area was extracted from Table-F.10 and summarizes in Table-F.26. Since twice or three times paddy culture is dominant in Tabanan (famous as rice storage), Badung, Gianyar and Bangli regencies, the target area extends less than 12% of total paddy area in regency.

On the other hand, one paddy culture followed by one or two *palawija* culture is dominant in Jembrana and Karangasem regencies. As a result, more than 50% of the total paddy area is the target for crop intensity improvement in these two regencies.

**Table-F.26 Target Area for Crop Intensity Improvement**

| No. | Regency | Paddy Area In 2003 (ha) | Ratio of Area less than 2 Paddy Cropping | Target Area to be improved (ha) | Cropping Pattern To be improved |
|---|---|---|---|---|---|
| 01 | Jembrana | 7,013 | 0.647 | 4,537 | A |
| 02 | Tabanan | 22,639 | 0.085 | 1,924 | A |
| 03 | Badung | 10,334 | 0.033 | 341 | A |
| 04 | Gianyar | 14,937 | 0.113 | 1,688 | A |
| 05 | Klungkung | 3,932 | 0.462 | 1,817 | A |
| 06 | Bangli | 2,888 | 0.111 | 321 | A |
| 07 | Karangasem | 7,034 | 0.550 | 3,869 | B |
| 08 | Buleleng | 11,011 | 0.232 | 2,555 | B |
| 71 | Denpasar | 2,856 | 0.385 | 1,100 | A |
| | Total | 82,644 | | 18,152 | |

Less than 2 paddy cropping: 1 paddy followed by *palawija*/vegetables/fallow
A: 1 Paddy (Nov.-Feb.) + 2 Paddy (Mar.-Jun.) + Other Crops without Irrigation
B: 1 Paddy (Dec.-Mar.) + 2 Paddy (Apr.-Jul.) + Other Crops without Irrigation

Utilizing the residual water, to examine how much area turns to two paddy culture is the effect evaluation of two alternative plans. Consequently, the necessity of water resources development, particularly storage facilities, was examined.

### (1) Alternative 1 (without Storage Facilities of Residual Water)

Since at least one paddy cropping is practiced in the most of area, the residual water is used for the second paddy starting from March or April depending on regency. The residual water during the cropping season of second paddy is applicable to increase the crop intensity of paddy. On the other hand, the residual water in the rest of season is not useful because of no storage facilities of water. Thus, the residual water during the second paddy season divided by the irrigation water requirement of second paddy is area increase of two paddy cropping. The result is summarized in Table-F.27.

With the Alternative 1 Plan, all target areas in Tabanan, Badung, Gianyar and Bangli regencies would be improved. As a result, crop intensity of paddy in those regencies would be more than 200% because 3 paddy cropping is also practiced. Although the residual water is enough to improve 10,800 ha, the improvement of crop intensity cannot reach to the maximum without an inter-region conveyance system to transfer the excess water from one region to another. In fact, the crop intensity in only 7,274 ha would be improved and the excess water would drain to the downstream.

Since the Alternative 1 Plan is the result of rehabilitation works of irrigation facilities and area decrease in paddy field, the crop intensity of paddy can be improved from one paddy cropping to two paddy cropping without any water resources development. Besides, paddy area to be improved by this plan (7,274 ha) is equivalent to 10% of the paddy area in 2025 (75,619 ha) showing its significance. Therefore, the Alternative 1 Plan is considered effective and feasible.

### (2) Alternative 2 (with Storage Facilities of Residual Water)

An idea of the Alternative 2 Plan is to store the residual water in the rest of second paddy season. The residual water stored is used to increase paddy culture. For the estimate of paddy area to be improved, the residual water stored was divided by the total irrigation water requirement for the second paddy ranging at 0.009 – 0.014 million $m^3$/ha.

The result is summarized in Table-F.27. With the Alternative 2 Plan, 200% crop intensity of paddy would be achieved in Buleleng and Denpasar regencies. 200% crop intensity of paddy could cover all regencies if the stored residual water was shared by all regencies; however, it is not feasible considering the cost for storage facilities and inter-region water conveyance.

**Table-F.27 Effect of Alternative Plans on Increase in Crop Intensity**

| No. | Regency | Target Area to be improved (ha) | Potential Area to be improved by Alternative 1 (ha) | Potential Area to be improved by Alternative 2 (ha) | Plan to achieve 200% crop intensity of paddy |
|---|---|---|---|---|---|
| 01 | Jembrana | 4,537 | ***300*** | 2,300 | none |
| 02 | Tabanan | ***1,924*** | 3,700 | 10,900 | Alternative 1 |
| 03 | Badung | ***341*** | 1,600 | 7,900 | Alternative 1 |
| 04 | Gianyar | ***1,688*** | 2,000 | 5,900 | Alternative 1 |
| 05 | Klungkung | 1,817 | ***400*** | 1,200 | none |
| 06 | Bangli | ***321*** | 500 | 1,000 | Alternative 1 |
| 07 | Karangasem | 3,869 | ***500*** | 1,400 | none |
| 08 | Buleleng | 2,555 | ***1,600*** | 3,900 | Alternative 2 |
| 71 | Denpasar | 1,100 | ***200*** | 1,200 | Alternative 2 |
| | Total | 18,152 | 10,800 | 35,700 | |

Total of Italics: Area to be improved by the Alternative 1 without inter-region conveyance system of water. 7,274ha.

The Alternative 2 Plan requires the development of storage facilities. The large storage facilities are not economically feasible as long as their purpose is irrigation. Instead, small farm ponds should be applied to use as much residual water as possible. Since the scale and location of farm ponds can be adjusted in accordance with the economic and technical evaluation, its feasibility is considered high despite the fact that development of small farm ponds would not be sufficient to store all residual water. Besides, small farm ponds are effective as drought countermeasures.

## F-2.6 Proposed Plans for Water Supply

Based on evaluation of two alternative plans, proposed plans for water supply are summarized as follows. Proposed plans are basically applicable to the whole Bali but particularly areas that require the Alternative 2 Plan for improvement of crop intensity as shown in Figure-F.19. Those areas extend in Buleleng, Karangasem, Klungkung, Denpasar and Jembrana; however, crop intensification might be less important in Denpasr because the paddy area in Denpasar is decreasing with urbanization.

- Small farm ponds would not have sufficient capacity to store all residual water but they are useful for maximum use of residual water and drought countermeasures. Thus, small farm ponds should be promoted.
- Crop diversification might require the irrigation system for fruit culture and horticulture on the dry land. In this case, the residual water is the first priority to be

used.

- The surface water development just for irrigation is not economically feasible. Therefore, the surface water development with multiple purposes including irrigation should be considered for improvement of crop intensity and drought countermeasures.
- The groundwater development is applicable to extend new irrigation schemes for fruit/vegetables culture. But the area of new irrigation schemes is limited because the most of arable land has been already used.
- For the poverty alleviation, mitigation of economic disparity in region and rural development, irrigation is effective but requires a subsidy. Since those purposes are subject to social matters, they cannot be examined by economic aspects. Thus, irrigation is promoted by the water resources development for those purposes.

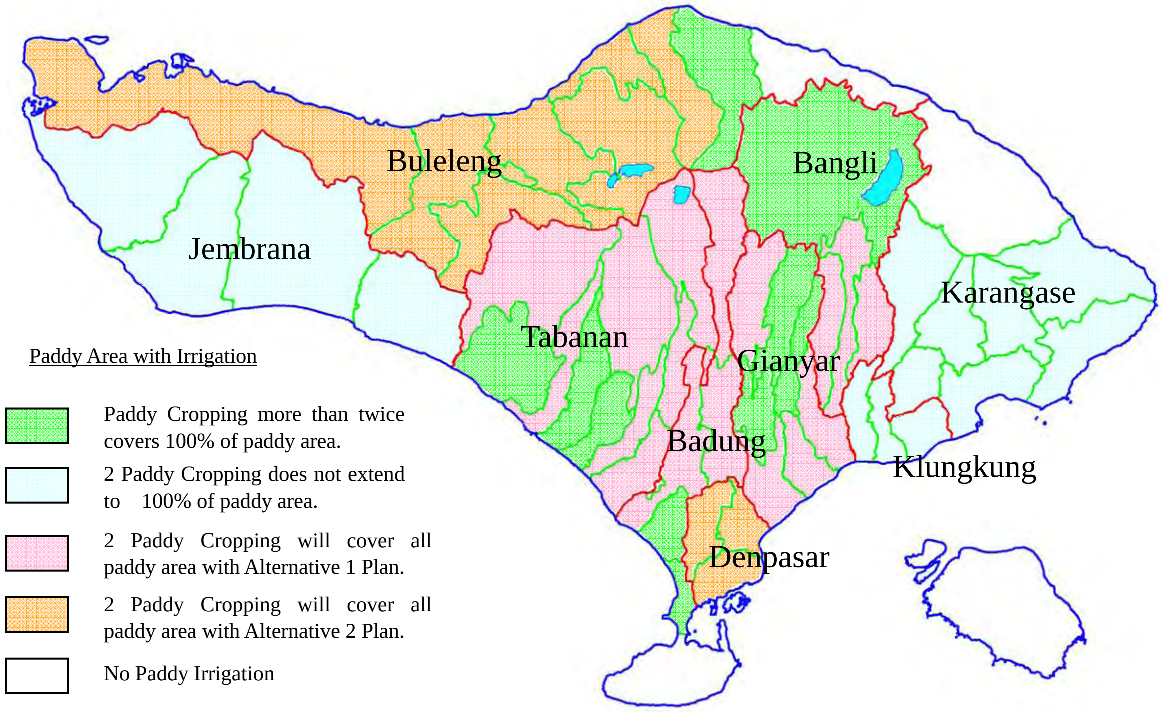



**Figure-F.19 Potential Area for Improvement of Crop Intensity**