

JAPAN INTERNATIONAL COOPERATION AGENCY  
DEPARTMENT OF WATER AFFAIRS  
MINISTRY OF AGRICULTURE, WATER AND RURAL DEVELOPMENT  
THE REPUBLIC OF NAMIBIA

THE STUDY  
ON  
THE GROUNDWATER POTENTIAL EVALUATION  
AND MANAGEMENT PLAN  
IN  
THE SOUTHEAST KALAHARI (STAMPRIET)  
ARTESIAN BASIN  
IN  
THE REPUBLIC OF NAMIBIA

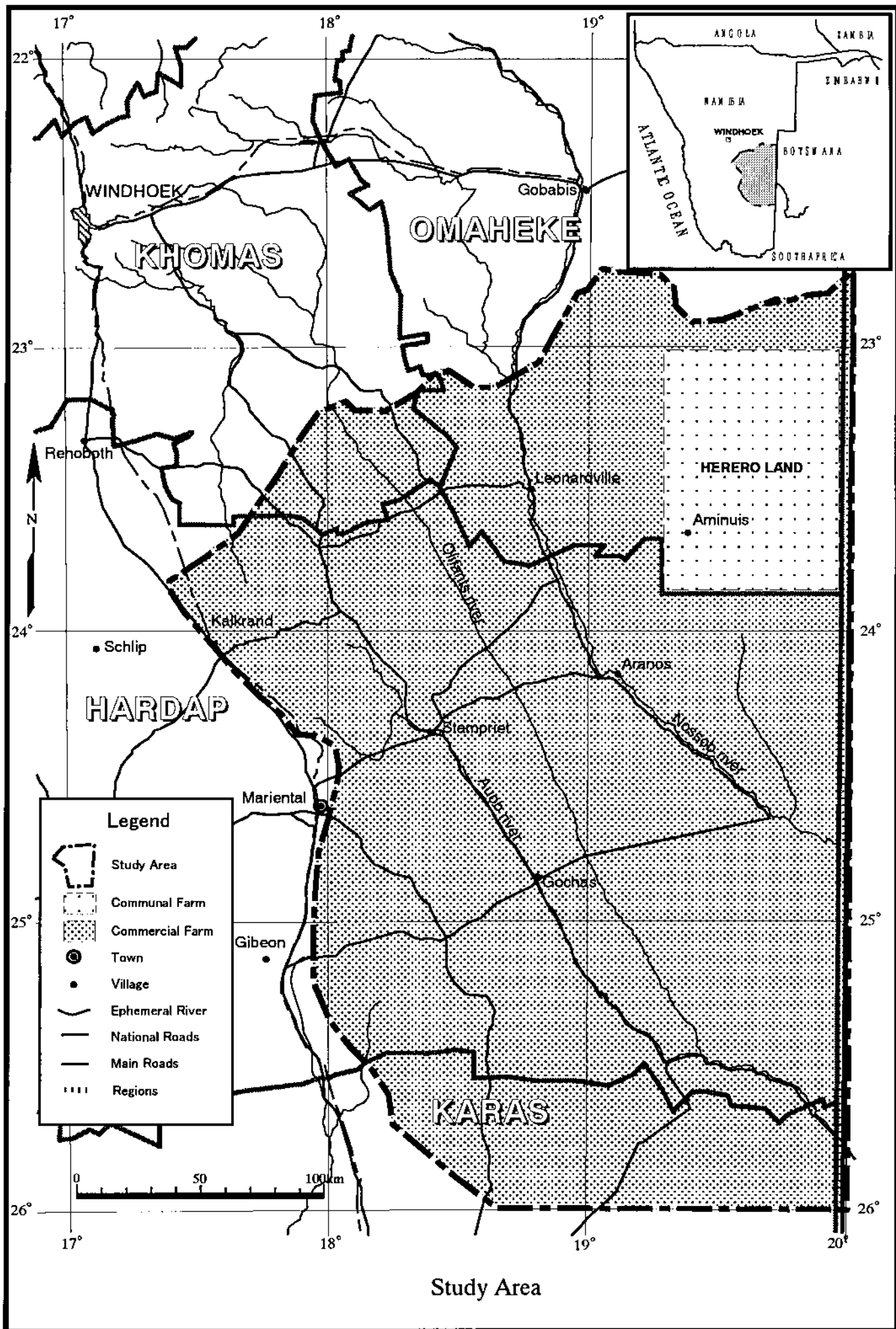
DRAFT FINAL REPORT

SUPPORTING REPORT

JANUARY 2002

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO  
IN ASSOCIATION WITH  
SANYU CONSULTANTS INC., TOKYO

Exchange rate on Feb.2002 is Namibian Dollar (\$N) =South African Rand (Zar)= Japanese Yen ¥11.70= US\$0.0877



Study Area

# TABLE OF CONTENTS

## SUPPORTING REPORT

SUMMARY

STUDY AREA

TABLE OF CONTENTS

List of Tables

List of Figures

Abbreviations

CHAPTER 1	INTRODUCTION .....	1 – 1
1.1	Background of the Study .....	1 - 1
1.2	Objectives of the Study .....	1 - 1
1.3	Study Area .....	1 - 2
1.4	Implementation of Study .....	1 - 2
CHAPTER 2	METEOROLOGY AND HYDROLOGY .....	2 - 1
2.1	Meteorology .....	2 - 1
2.1.1	Meteorological Network.....	2 - 1
2.1.2	General Climate.....	2 - 1
2.2	Hydrology.....	2 - 9
2.2.1	General .....	2 - 9
2.2.2	Drainage Systems .....	2 - 9
2.2.3	Study Area Related Rivers .....	2 - 10
2.2.4	Water Balance .....	2 - 19
2.2.5	Issues .....	2 - 19
CHAPTER 3	GEOMORPHOLOGY.....	3 - 1
3.1	General Geomorphology .....	3 - 1
3.2	Methodology of Geomorphologic Analysis .....	3 - 1
3.3	Geomorphologic Characteristics .....	3 - 3
CHAPTER 4	GEOLOGY.....	4 - 1
4.1	General Geology.....	4 - 1

4.2	Geological Description.....	4 - 3
4.2.1	Pre-Karoo Basement.....	4 - 3
4.2.2	Karoo Sequence.....	4 - 3
4.2.3	Kalahari Beds .....	4 - 13
4.3	Geological Structure.....	4 - 15
4.3.1	Cross Section.....	4 - 15
4.3.2	Lineaments and Faults.....	4 - 15
CHAPTER 5 GEOPHYSICAL SURVEY.....		5 - 1
5.1	Purpose of Survey .....	5 - 1
5.2	Time Domain Electro-magnetic Survey (TEM Method) .....	5 - 1
5.2.1	Survey Area.....	5 - 1
5.2.2	Survey Method and Interpretation Procedures .....	5 - 1
5.2.3	Survey Results.....	5 - 4
5.2.4	Conclusions .....	5 - 12
5.3	Aeromagnetic Survey .....	5 - 12
5.3.1	Survey Area.....	5 - 12
5.3.2	Survey Method and Interpretation Procedures .....	5 - 12
5.3.3	Survey Results.....	5 - 13
CHAPTER 6 TEST BOREHOLE .....		6 - 1
6.1	Drilling Program.....	6 - 1
6.1.1	Outline of the Program.....	6 - 1
6.1.2	Structure and Specification .....	6 - 2
6.1.3	Drilling Procedure .....	6 - 5
6.1.4	Materials Used.....	6 - 8
6.1.5	Drilling Method.....	6 - 11
6.1.6	Sampling, Measurement and Testing .....	6 - 13
6.1.7	Borehole Logging.....	6 - 15
6.1.8	Result of Drilling.....	6 - 18
6.2	Pumping Test.....	6 - 37
6.2.1	Outline of the Test.....	6 - 37
6.2.2	Measurement .....	6 - 38
6.2.3	Method of Analysis .....	6 - 39
6.2.4	Borehole Hydraulics .....	6 - 43
6.2.5	Aquifer Constants.....	6 - 45

6.2.6	Interaction Between the Aquifers .....	6 - 47
6.2.7	Pumping Test Analysis of Existing Boreholes.....	6 - 48
6.3	Installation of Water Level Recorder .....	6 - 61
6.3.1	Recorders, Installed .....	6 - 61
6.3.2	Specification of Water Level Recorder .....	6 - 61
6.3.3	Technical Transfer on Operation and Maintenance of the Recorder.....	6 - 62
6.3.4	Recommendation on Operation and Maintenance .....	6 - 63
<b>CHAPTER 7 WATER QUALITY AND ISOTOPE ANALYSIS .....</b>		<b>7 - 1</b>
7.1	Introduction .....	7 - 1
7.1.1	Background and Need for Study .....	7 - 1
7.1.2	Terms of Reference .....	7 - 2
7.1.3	Parallel IAEA Project Coordination and Linkage to JICA Project .....	7 - 2
7.2	Hydrochemical Information .....	7 - 3
7.2.1	Utilization of Hydrochemical Information.....	7 - 3
7.2.2	Sources and Extent of Existing Chemical Data from Earlier Surveys ..	7 - 3
7.2.3	Electronic Capturing of Earlier Data.....	7 - 5
7.2.4	Present JICA Project Surveys.....	7 - 5
7.2.5	Present IAEA Project Surveys.....	7 - 6
7.2.6	Changes of Water Quality with Time.....	7 - 7
7.2.7	Linking of Earlier Data with Present JICA and IAEA Project Information.....	7 - 7
7.2.8	Hydrochemical Profiles .....	7 - 9
7.3	Stable and Radioactive Isotope Information .....	7 - 10
7.3.1	Utilization of Isotope Information in Hydrogeology.....	7 - 10
7.3.2	Sources and Extent of Existing Isotope Data from Earlier Surveys .....	7 - 14
7.3.3	Present JICA Project Surveys.....	7 - 15
7.3.4	Present IAEA Project Surveys.....	7 - 15
7.3.5	Linking of Earlier Data with Present JICA and IAEA Project Information.....	7 - 17
7.4	Evaluation and Interpretation of Aquifer Hydrochemistry.....	7 - 17
7.4.1	Hydrochemical Evolution in Each Aquifer .....	7 - 17
7.4.2	Water Quality Trends with Time.....	7 - 23
7.4.3	Hydrochemical Profiles .....	7 - 24
7.4.4	Environmental Radioisotope Determination and the “Age “ of the Groundwater.....	7 - 30

7.4.5	Stable Environmental Isotope Results.....	7 - 31
7.4.6	Discussion of Hydrochemical Evolution.....	7 - 33
7.4.7	Extent of Area with Suitable Water Quality for Various Purposes.....	7 - 34
7.4.8	Borehole Leakage and Quality Deterioration .....	7 - 35
7.5	Isotope and Chemical Evaluation of Aquifer Recharge .....	7 - 36
7.5.1	Conceptual Hydrogeological Model.....	7 - 36
7.6	Conclusions .....	7 - 38
7.6.1	Insights Gained into Hydrogeology.....	7 - 38
7.6.2	Increasing Groundwater Salinity with Time .....	7 - 39
7.6.3	Adequacy of Existing Information .....	7 - 39
7.7	Recommendations .....	7 - 40
7.7.1	Further Information Needs .....	7 - 40
7.7.2	Increase in Groundwater Salinity .....	7 - 40
7.7.3	Down-the-Hole Hydrochemical Logging of Boreholes.....	7 - 40
7.7.4	Safeguarding of Collected Information .....	7 - 40
<b>CHAPTER 8 HYDROGEOLOGY .....</b>		<b>8 - 1</b>
8.1	Existing Database and Hydrocensus .....	8 - 1
8.1.1	Groundwater Database of DWA .....	8 - 1
8.1.2	Hydrocensus .....	8 - 1
8.2	Definition of Aquifer.....	8 - 4
8.3	Structure of Aquifers .....	8 - 4
8.3.1	Distribution of Aquifer.....	8 - 4
8.3.2	Hydrogeological Map and Cross Sections .....	8 - 16
8.4	Groundwater Level.....	8 - 27
8.4.1	Elevation Survey .....	8 - 27
8.4.2	Distribution of Piezometric Head.....	8 - 27
8.4.3	Fluctuation of Piezometric Head.....	8 - 28
8.5	Groundwater Quality .....	8 - 56
8.6	Groundwater Recharge and Macro Water Balance .....	8 - 61
8.6.1	Precipitation .....	8 - 61
8.6.2	Groundwater Recharge.....	8 - 62
8.6.3	River Discharge.....	8 - 69
8.6.4	Groundwater Discharge.....	8 - 70
8.6.5	Evapo-transpiration .....	8 - 70
8.6.6	Macro Water Balance in the Basin.....	8 - 72

CHAPTER 9	EXISTING WATER SUPPLY SYSTEM AND SEWERAGE SYSTEM .	9 - 1
9.1	Existing Water Supply System.....	9 - 1
9.1.1	Outline of the Water Supplying System.....	9 - 1
9.1.2	Population and Areas Served .....	9 - 2
9.1.3	Unit Water Requirement .....	9 - 2
9.1.4	Standard for Portable Water .....	9 - 3
9.1.5	Water Supply Facilities .....	9 - 3
9.1.6	Organization, Operation and Maintenance.....	9 - 4
9.1.7	Current Bulk Water Supply Tariffs .....	9 - 7
9.2	Existing Sewerage System .....	9 - 7
9.2.1	Service Area and Population .....	9 - 7
9.2.2	Waste Water Facilities .....	9 - 7
CHAPTER 10	EXISTING WATER USE.....	10 - 1
10.1	Current Water Use and Supply Systems .....	10 - 1
10.1.1	Villages.....	10 - 1
10.1.2	Domestic Water in the Commercial Farms .....	10 - 1
10.1.3	Domestic Water in the Communal Lands .....	10 - 2
10.1.4	Industries .....	10 - 2
10.1.5	Tourism .....	10 - 2
10.1.6	Stock Watering.....	10 - 2
10.1.7	Irrigation.....	10 - 3
10.1.8	Estimated Present Water Consumption in the Study Area.....	10 - 12
CHAPTER 11	GROUNDWATER POTENTIAL EVALUATION .....	11 - 1
11.1	Introduction .....	11 - 1
11.2	Storage of Groundwater .....	11 - 1
11.2.1	Volume of Aquifer .....	11 - 1
11.2.2	Aquifer Characteristic .....	11 - 3
11.2.3	Aquifer Storage .....	11 - 3
11.3	Groundwater Potential Evaluation .....	11 - 4
11.3.1	Groundwater Depth .....	11 - 5
11.3.2	Groundwater Quality .....	11 - 6
11.3.3	Depth of Aquifer .....	11 - 10
11.3.4	Specific Yield.....	11 - 10
11.3.5	Potential Evaluation of Aquifer.....	11 - 16



CHAPTER 12	GROUNDWATER MODELLING .....	12 - 1
12.1	Groundwater Basin Management and Groundwater Modelling.....	12 - 1
12.1.1	Permissible Yield .....	12 - 1
12.1.2	Work Elements of Groundwater Basin Management.....	12 - 2
12.2	General Procedure of Groundwater Simulation .....	12 - 4
12.2.1	Aquifer Modeling.....	12 - 4
12.2.2	Data Manipulation.....	12 - 4
12.2.3	Calibration of Model .....	12 - 5
12.2.4	Model Prediction and Evaluation .....	12 - 5
12.3	Description of Numerical Model.....	12 - 5
12.3.1	Introduction .....	12 - 5
12.3.2	Groundwater Flow Model .....	12 - 6
12.4	Conceptual Model .....	12 - 9
12.4.1	Hydrogeologic Condition .....	12 - 9
12.4.2	Aquifer System.....	12 - 10
12.5	Data Manipulation.....	12 - 10
12.5.1	Grid Design .....	12 - 10
12.5.2	Elevation of Top and Bottom of Layers .....	12 - 11
12.5.3	Boundary Condition .....	12 - 12
12.5.4	Aquifer Constants.....	12 - 12
12.5.5	Groundwater Levels .....	12 - 13
12.5.6	Pumpage .....	12 - 13
12.5.7	Recharge.....	12 - 17
12.6	Model Calibration .....	12 - 20
12.6.1	Procedure of Model Calibration .....	12 - 20
12.6.2	Calibrated Model.....	12 - 20
12.7	Model Prediction .....	12 - 23
12.7.1	Prediction Cases .....	12 - 23
12.7.2	Constraints on Permissible Yield .....	12 - 24
12.7.3	Model Prediction .....	12 - 25
12.8	Evaluation of Permissible Yield.....	12 - 28
12.8.1	Permissible Yield in the Basin .....	12 - 28
12.8.2	Future Improvement in Modelling .....	12 - 31
CHAPTER 13	SOCIO-ECONOMIC ASPECTS .....	13 - 1
13.1	National Level .....	13 - 1

13.1.1	Administration.....	13 - 1
13.1.2	Socio-cultural Profiles.....	13 - 1
13.1.3	Economic Activities .....	13 - 3
13.1.4	Infrastructure .....	13 - 6
13.1.5	Financial Situation.....	13 - 8
13.2	Socio-economy in the Study Area.....	13 - 24
13.2.1	Administration.....	13 - 24
13.2.2	Population.....	13 - 24
13.2.3	Ethnic Groups.....	13 - 24
13.2.4	Culture and Custom.....	13 - 25
13.2.5	Livelihood of the People .....	13 - 25
13.2.6	Income and Expenditures .....	13 - 25
13.2.7	Trend of Livestock and Agriculture .....	13 - 26
13.2.8	Industries and Its Products.....	13 - 27
13.2.9	Tourism .....	13 - 27
13.2.10	Infrastructure and Public Services.....	13 - 27
13.2.11	Employment Condition of Farm Workers.....	13 - 28
13.2.12	Disposition of Waste Water and Solid Waste .....	13 - 28
13.2.13	Commodity Prices .....	13 - 29
CHAPTER 14 ENVIRONMENTAL ASPECT .....		14 - 1
14.1.	Introduction .....	14 - 1
14.2	Initial Environmental Assessment.....	14 - 3
14.3	Social Environment .....	14 - 3
14.3.1	Resettlement by Land Occupation.....	14 - 3
14.3.2	Economic Activities .....	14 - 4
14.3.3	Traffic and Public Facilities .....	14 - 5
14.3.4	Split of Communities .....	14 - 5
14.3.5	Cultural Property .....	14 - 5
14.3.6	Water Rights and Rights of Common .....	14 - 6
14.3.7	Public Health Condition.....	14 - 7
14.3.8	Waste.....	14 - 8
14.3.9	Hazards.....	14 - 9
14.4	Natural Environment .....	14 - 10
14.4.1	Topography and Geology .....	14 - 10
14.4.2	Soil Erosion.....	14 - 10

14.4.3	Groundwater.....	14 - 10
14.4.4	Hydrological Situation .....	14 - 11
14.4.5	Coastal Zone.....	14 - 13
14.4.6	Fauna and Flora.....	14 - 13
14.4.7	Meteorology .....	14 - 15
14.4.8	Landscape.....	14 - 15
14.5	Pollution .....	14 - 15
14.5.1	Air Pollution.....	14 - 15
14.5.2	Water Pollution .....	14 - 15
14.5.3	Soil Contamination.....	14 - 16
14.5.4	Noise and Vibration .....	14 - 16
14.5.5	Land Subsidence.....	14 - 16
14.5.6	Offensive Odour.....	14 - 17
14.6	Discussion .....	14 - 21
14.7	Conclusions .....	14 - 23
14.8	Recommendations .....	14 - 23
 CHAPTER 15 ECONOMIC VALUE OF GROUNDWATER .....		 15 - 1
15.1	Analysis of Value Added of Irrigation and Livestock Farming by Using Generalised Data.....	15 - 1
15.1.1	Spectral Water Use.....	15 - 1
15.1.2	Economy of Irrigation and Livestock Farming .....	15 - 1
15.1.3	Estimation of Water Fee for Groundwater.....	15 - 2
15.1.4	Estimation of Value Added of Farming Activities.....	15 - 3
15.2	Analysis of Mitigation Measures.....	15 - 6
15.2.1	Main Problems in the Study Area .....	15 - 6
15.2.2	The ‘Optimal Depletion’ for Sustainable Ground Water Use.....	15 - 6
15.2.3	Possible Applicable Methods for Saving of Irrigation Water Use.....	15 - 7

## References

## APPENDICES

- Appendix A Namibia's Environmental Assessment Policy
- Appendix B Guidelines for Environmental Assessments for New Boreholes
- Appendix C Guidelines for Environmental Assessments for Large Irrigation Projects
- Appendix D Occurrence of Amphibians, Reptiles, and Mammals in National (MET)  
Protected Areas
- Appendix E Application for a Waste Water Discharge Permit
- Appendix F Wastewater Disposal at Towns, Villages and Schools  
in the Stampriet Artesian Basin
- Appendix G Listing of Hotels and Guest Houses in the Stampriet Artesian Basin
- Appendix H General Standards for Effluents and Sewage
- Appendix I Log of Boring J-1 – J-9
- Appendix J Hydrocensus Format

## LIST OF TABLES

Table 1.4-1	Total Schedule of the Study .....	1 - 3
Table 1.4-2	Member List .....	1 - 4
Table 3.2-1	List of LANDSAT Image Data .....	3 - 1
Table 3.3-1	Geomorphologic Interpretation Chart .....	3 - 3
Table 4.1-1	Stratigraphy of the Stampriet Artesian Basin .....	4 - 2
Table 4.2-1	Description of Nossob Member .....	4 - 5
Table 4.2-2	Description of Auob Member.....	4 - 7
Table 6.1-1	Summary of Test Borehole Data .....	6 - 25
Table 6.1-2	Depth and Thickness of the Each Formation .....	6 - 27
Table 6.1-3	The Aquifers which Water Samples are Taken, and the Items Analysed .....	6 - 28
Table 6.1-4	Results of Water Quality and Isotope Analysis of JICA Test Boreholes ..	6 - 29
Table 6.1-5	Results of Water Quality and Isotope Analysis of Specified Aquifer in JICA of Test Boreholes .....	6 - 30
Table 6.2-1	Summary of Borehole Hydraulics .....	6 - 49
Table 6.2-2	Summary of Aquifer Constants of Test Boreholes.....	6 - 52
Table 6.2-3	Analyzed Aquifer Constants of Existing Boreholes.....	6 - 53
Table 6.3-1	Data Related to Water Level Recorder for Test Borehole.....	6 - 64
Table 6.3-2	Data Related to Water Level Recorder for Existing Borehole .....	6 - 66
Table 7.1	Results of Duplicate Samples Submitted to NamWater for Analysis .....	7 - 42
Table 7.2	PCI Groundwater Chemistry Survey Boreholes also Previously Sampled and Analysed by DWA.....	7 - 43
Table 7.3	Water Quality Changes Over a Period of Two to Three Decades in the Artesian Basin .....	7 - 44
Table 7.4	List of Boreholes Logged Hydrochemically Down the Hole .....	7 - 45
Table 7.5	The Threat Leaky Boreholes Pose to Groundwater Quality.....	7 - 46
Table 8.1-1	Number of Returns in Each Survey Item.....	8 - 3
Table 8.6-1	Catchment Area.....	8 - 61
Table 8.6-2	Precipitation Volume in Ordinary Year and '99-'00 Rainy Season .....	8 - 62
Table 8.6-3	Results of Water Level Monitoring in Kalahari Aquifer.....	8 - 63
Table 8.6-4	Aquifer Contents of Kalahari Aquifer.....	8 - 63

Table 8.6-5	Results of Water Level Monitoring in Auob Aquifer .....	8 - 66
Table 8.6-6	Observation Results of Auob River Discharge in '99-'00 Rainy Season...	8 - 70
Table 8.6-7	Outflow of Groundwater .....	8 - 70
Table 9.1-1	Unit Water Requirement .....	9 - 3
Table 9.2-1	Type of Toilet in Hardap Region.....	9 - 7
Table 9.2-2	Treatment Systems in Village Centers. ....	9 - 8
Table 10.1-1	Population and Areas Served .....	10 - 1
Table 10.1-2	Water Supply Scheme by Namwater.....	10 - 1
Table 10.1-3	Domestic Water Uses on the Commercial Farms .....	10 - 2
Table 10.1-4	Stock Watering.....	10 - 3
Table 10.1-5	Irrigation Area and Irrigation Water Use.....	10 - 4
Table 10.1-6	Irrigation Area by Crop Types.....	10 - 5
Table 10.1-7	Permitted Water Allocations .....	10 - 6
Table 10.1-8	Illegal Farmers in Area II .....	10 - 7
Table 10.1-9	Illegal Farmers in Area VII.....	10 - 7
Table 10.1-10	Comparison Between Actual Water Use and Permitted Water Use.....	10 - 9
Table 10.1-11	Irrigation Area by Applied Methods in the Study Area .....	10 - 11
Table 11.2-1	Volume of Kalahari Aquifer.....	11 - 1
Table 11.2-2	Volume of Kalahari Aquifer Above Water Level .....	11 - 1
Table 11.2-3	Volume of Auob Aquifer .....	11 - 2
Table 11.2-4	Volume of Nossob Aquifer .....	11 - 2
Table 11.2-5	Porosity of Aquifer .....	11 - 3
Table 11.2-6	Groundwater Quantities within the Aquifers .....	11 - 3
Table 11.3.1	Index for Evaluation of Aquifers.....	11 - 4
Table 12-1	Hydrogeological Structure in the Stampriet Artesian Basin .....	12 - 33
Table 12-2	Combination of Aquifers and Aquitards .....	12 - 33
Table 12-3	Combination of Aquifers and Aquitard for Each Cell .....	12 - 34
Table 12-4	Procedure of Aquifer Allotment to Model Layer .....	12 - 35
Table 12-5	Bottom Elevation of Model Layer 1.....	12 - 36
Table 12-6	Bottom Elevation of Model Layer 2.....	12 - 37
Table 12-7	Bottom Elevation of Model Layer 3.....	12 - 38
Table 12-8	Bottom Elevation of Model Layer 4.....	12 - 39
Table 12-9	Bottom Elevation of Model Layer 5.....	12 - 40
Table 12-10	Bottom Elevation of Model Layer 6.....	12 - 41
Table 12-11	Data Source and Estimation Method of Present Groundwater Use .....	12 - 42
Table 12-12	Results of the Hydorcensus .....	12 - 42

Table 12-13	Productions of NamWater Scheme .....	12 - 43
Table 12-14	Estimated Irrigation Uses of Permit Holders.....	12 - 43
Table 12-15	Estimation of Unit Consumption from Irrigation Permits.....	12 - 44
Table 12-16	Used Assumptions for Groundwater Use Estimation.....	12 - 44
Table 12-17	Present Groundwater Use.....	12 - 45
Table 12-18	Procedure of Groundwater Use Dividing into Aquifers.....	12 - 45
Table 12-19	Present Groundwater Use by Aquifer.....	12 - 46
Table 12-20	Estimation Sources of Groundwater Use Variation 1990-1999 .....	12 - 46
Table 12-21	Results of Hydrocensus 1986-1989.....	12 - 47
Table 12-22	Comparison of Results of Hydrocensus Between 1986-1989 and 1999 .....	12 - 48
Table 12-23	Variation of Groundwater Use .....	12 - 49
Table 12-24	Estimated Annual Discharge and Recharge Rates .....	12 - 50
Table 12-25	Fixed Hydraulic Conductivity and Storage Coefficient .....	12 - 50
Table 12-26	Fixed Recharge Rate .....	12 - 51
Table 12-27	Future Pumping Plans .....	12 - 51
Table 13.1-1	Socio-economic Indicators of Namibia.....	13 - 11
Table 13.1-2	Total Population and Population Density by 1970, 1981 and 1991* .....	13 - 12
Table 13.1-3	Distribution of Employed Persons Aged 15 Years and Above by Sex and Industry, 1991 Census .....	13 - 13
Table 13.1-4	Annual Household Incomes in Region.....	13 - 13
Table 13.1-5	Gross Domestic Product by Activity.....	13 - 14
Table 13.1-6	Gross Domestic Product by Activity.....	13 - 14
Table 13.1-7	Gross Domestic Product by Activity, Percentage Contributions .....	13 - 15
Table 13.1-8	Actual and Forecast Real Growth in GDP by Sector 1990-2000.....	13 - 15
Table 13.1-9	Export of Goods and Services.....	13 - 16
Table 13.1-10	Import of Goods and Services .....	13 - 16
Table 13.1-11	Imports by Country.....	13 - 17
Table 13.1-12 (1)	Consumer Price Index-All Items Index (Base December 1992=1).....	13 - 18
Table 13.1-12 (2)	Consumer Price Index-All Items Inflation Rate (%).....	13 - 18
Table 13.1-13	Electricity Generation and Supply.....	13 - 19
Table 13.1-14	Namibia Financial Operation of the Central Government, 1989/90-1995/96 N\$ Millions.....	13 - 20
Table 13.1-15	Government Consumption Expenditure at Current Prices .....	13 - 21
Table 13.1-16	Government Consumption Expenditure in Percentage .....	13 - 21
Table 13.1-17	Foreign Development Assistance to Namibia.....	13 - 22

Table 13.1-18	Annual Growth Rate of Gross Domestic Product by Activity .....	13 - 22
Table 13.2-1	Comparison of Indicators .....	13 - 30
Table 13.2-2	Hardap Region.....	13 - 31
Table 13.2-3	Karas Region .....	13 - 32
Table 13.2-4	Khom as Region .....	13 - 33
Table 13.2-5	Omaheke Region .....	13 - 34
Table 14-1	Screening for Groundwater Development: Social Environment.....	14 - 18
Table 14-2	Screening for Groundwater Development: Natural Environment.....	14 - 19
Table 14-3	Screening for Groundwater Development: Pollution.....	14 - 20
Table 14-4	Overall Evaluation for Groundwater Development .....	14 - 22
Table 15.1-1	Sectoral Water Use.....	15 - 1
Table 15.1-2	Cost and Benefit from Irrigation and Livestock.....	15 - 2
Table 15.1-3	Estimation of Value Added of Livestock Productions in the Study Area.	15 - 4
Table 15.1-4	Value Added per Cubic Meter of Water by Crop.....	15 - 4
Table 15.1-5	Estimated Total Value Added in the Study Area .....	15 - 4
Table 15.1-6	Estimation of Water Price for Groundwater.....	15 - 5
Table 15.2-1	Minimum Requirements for Different Crops and Irrigation Methods .....	15 - 10
Table 15.2-2	Water Saving Volume with Application of Micro Irrigation Methods .....	15 - 11
Table 15.2-3	Irrigation Areas by Methods.....	15 - 12
Table 15.2-4	Value Added of Crops.....	15 - 14



## LIST OF FIGURES

Fig. 2.1-1	Location of Meteorological Stations .....	2 - 5
Fig. 2.1-2	Location of Rainfall Stations.....	2 - 6
Fig. 2.1-3	Average Annual Rainfall.....	2 - 7
Fig. 2.1-4	Annual Evaporation.....	2 - 7
Fig. 2.1-5	Monthly Means of Maximum and Minimum Temperature .....	2 - 8
Fig. 2.2-1	Main Drainage Catchments of Namibia.....	2 - 21
Fig. 2.2-2	Study Area Related Catchment .....	2 - 22
Fig. 3.1-1	Topographic Map of the Study Area.....	3 - 2
Fig. 3.3-1	Geomorphologic Interpretation Map.....	3 - 4
Fig. 4.2-1	Geological Map of the Southeast Kalahari Artesian Basin.....	4 - 14
Fig. 4.3-1	Location Map of Geological Cross Section.....	4 - 16
Fig. 4.3-2	Geological Cross Section-1 .....	4 - 17
Fig. 4.3-3	Geological Cross Section-2.....	4 - 18
Fig. 4.3-4	Geological Cross Section-3.....	4 - 19
Fig. 4.3-5	Geological Cross Section-4.....	4 - 20
Fig. 4.3-6	Geological Cross Section-5.....	4 - 21
Fig. 4.3-7	Geological Cross Section-6.....	4 - 22
Fig. 4.3-8	Geological Cross Section-7.....	4 - 23
Fig. 4.3-9	Geological Cross Section-8.....	4 - 24
Fig. 5.2-1	TDEM Sounding Positions.....	5 - 2
Fig. 5.2-2	Resistivity Profile C .....	5 - 5
Fig. 5.2-3	Resistivity Plan at 800m AMSL Based on Smooth Modelling.....	5 - 6
Fig. 5.2-4	Resistivity Plan at 900m AMSL Based on Smooth Modelling.....	5 - 7
Fig. 5.2-5	Resistivity Plan at 1000m AMSL Based on Smooth Modelling.....	5 - 8
Fig. 5.3-1	Aeromagnetic Anomaly.....	5 - 14
Fig. 5.3-2	Aeromagnetic Interpretation Map .....	5 - 15
Fig. 6.1-1	Location Map of Test Boreholes .....	6 - 31
Fig. 6.1-2	Standard Design, Kalahari Test Borehole .....	6 - 32
Fig. 6.1-3	Standard Design, Auob Test Boreholes .....	6 - 33
Fig. 6.1-4	Standard Design, Nossob Test Borehole.....	6 - 34
Fig. 6.1-5	Concrete Head Block for Test Borehole .....	6 - 35

Fig. 6.1-6	Borehole Head Facilities .....	6 - 36
Fig. 6.2-1	Distribution of Aquifer Constants in Each Aquifer.....	6 - 54
Fig. 6.2-2	Interaction Between the Aquifers, in Location J2. ....	6 - 55
Fig. 6.2-3	Interaction Between the Aquifers, in Location J3. ....	6 - 56
Fig. 6.2-4	Interaction Between the Aquifers, in Location J4. ....	6 - 57
Fig. 6.2-5	Interaction Between the Aquifers, in Location J6. ....	6 - 58
Fig. 6.2-6	Interaction Between the Aquifers, in Location J7. ....	6 - 59
Fig. 6.2-7	Interaction Between the Aquifers, in Location J8. ....	6 - 60
Fig. 6.3-1	Location Map of Boreholes with Installed Water Level Recorder.....	6 - 67
Fig. 6.3-2 (1)	Borehole Head Facilities and Water Level Recorder .....	6 - 68
Fig. 6.3-2 (2)	Borehole Head Facilities and Water Level Recorder (only for Location J4 and J7).....	6 - 69
Fig. 6.3-3	Borehole Head Facilities and Water Level Recorder (Pressure Probe Type) .....	6 - 70
Fig. 7.1a	Sampling Points in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 47
Fig. 7.1b	Sampling Points in the Auob Aquifer .....	7 - 48
Fig. 7.1c	Sampling Points in the Nossob Aquifer .....	7 - 49
Fig. 7.2a	Electrical Conductivity (EC) in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 50
Fig. 7.2b	Electrical Conductivity (EC) in the Auob Aquifer.....	7 - 50
Fig. 7.2c	Electrical Conductivity (EC) in the Nossob Aquifer.....	7 - 50
Fig. 7.3a	Chloride Concentrations in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 51
Fig. 7.3b	Chloride Concentrations in the Auob Aquifer .....	7 - 51
Fig. 7.3c	Chloride Concentrations in the Nossob Aquifer .....	7 - 51
Fig. 7.4a	Sulphate Concentrations in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 52
Fig. 7.4b	Sulphate Concentrations in the Auob Aquifer .....	7 - 52
Fig. 7.4c	Sulphate Concentrations in the Nossob Aquifer .....	7 - 52
Fig. 7.5a	Nitrate Concentrations in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 53
Fig. 7.5b	Nitrate Concentrations in the Auob Aquifer .....	7 - 53
Fig. 7.5c	Nitrate Concentrations in the Nossob Aquifer .....	7 - 53
Fig. 7.6a	Potassium Concentrations in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 54

Fig. 7.6b	Potassium Concentrations in the Auob Aquifer .....	7 - 54
Fig. 7.6c	Potassium Concentrations in the Nossob Aquifer.....	7 - 54
Fig. 7.7a	Silica Concentrations in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 55
Fig. 7.7b	Silica Concentrations in the Auob Aquifer .....	7 - 55
Fig. 7.7c	Silica Concentrations in the Nossob Aquifer .....	7 - 55
Fig. 7.8a	Sodium Percentage (me/L) in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 56
Fig. 7.8b	Sodium Percentage (me/L) in the Auob Aquifer.....	7 - 56
Fig. 7.8c	Sodium Percentage (me/L) in the Nossob Aquifer.....	7 - 56
Fig. 7.9a	Bicarbonate Percentage (me/L) in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 57
Fig. 7.9b	Bicarbonate Percentage (me/L) in the Auob Aquifer.....	7 - 57
Fig. 7.9c	Bicarbonate Percentage (me/L) in the Nossob Aquifer.....	7 - 57
Fig. 7.10	Water Quality (EC) Changes Over Several Decades .....	7 - 58
Fig. 7.11a	Location of Hydrochemically Logged Boreholes (WW Borehole Numbers) .....	7 - 59
Fig. 7.11b	Hydrochemical Profiles for DWA Recorder Borehole WW10120 on Farm Boomplass, R386 .....	7 - 60
Fig. 7.11c	Hydrochemical Profiles for Borehole WW10185 at the Roads Camp on Farm Neu Loore, M97 .....	7 - 60
Fig. 7.11d	Hydrochemical Profiles for DWA Recorder Borehole WW22544 on Farm Olifantswater West, M102.....	7 - 61
Fig. 7.11e	Hydrochemical Profiles for Observation Borehole WW22837 (JO-4A) on Farm Tugela, R212. ....	7 - 61
Fig. 7.11f	Hydrochemical Profiles for DWA Recorder Borehole WW32457 on Farm Spes Bona, R132.....	7 - 62
Fig. 7.11g	Hydrochemical Profiles for Unused Borehole WW33038 on Farm Donnersberg, L29.....	7 - 62
Fig. 7.11h	Hydrochemical Profiles for Newly Drilled Borehole WW37468 in Leonardville, Erf No 33.....	7 - 63
Fig. 7.11i	Hydrochemical Profiles for Borehole WW35769 on Farm Naomi, R455	7 - 63
Fig. 7.11j	Hydrochemical Profiles for Observation Borehole WW37225 (JO-7A) on Farm Glencoe, R78.....	7 - 64
Fig. 7.11k	Hydrochemical Profiles for Borehole WW37226 on Farm Goamus, R70.....	7 - 64

Fig. 7.11l	Hydrochemical Profiles for Borehole WW37227 on Farm Nooitgedacht, R164.....	7 - 65
Fig. 7.11m	Hydrochemical Profiles for Borehole WW37228 on Farm Nooitgedacht, R164.....	7 - 65
Fig. 7.11n	Hydrochemical Profiles for Borehole WW39839 (J1A) on Farm Christiana L727.....	7 - 66
Fig. 7.11o	Hydrochemical Profiles for Borehole WW39840 (J2A) on Farm Olifantswater West, M102.....	7 - 66
Fig. 7.11p	Second set of Hydrochemical Profiles for Borehole WW39840 (J2A) on Farm Olifantswater West, M102.....	7 - 67
Fig. 7.11q	Hydrochemical Profiles for Borehole WW39841 (J2N) on Farm Olifantswater West, M102.....	7 - 67
Fig. 7.11r	Hydrochemical Profiles for Observation Borehole WW39873 (JO-2A) on Farm Gumuchab Ost, M94.....	7 - 68
Fig. 7.11s	Hydrochemical Profiles for Borehole WW6921 on Farm Ou Dempster, R356. ....	7 - 68
Fig. 7.12a	Carbon-14 Groundwater Age in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 69
Fig. 7.12b	Carbon-14 Groundwater Age in the Auob Aquifer .....	7 - 69
Fig. 7.12c	Carbon-14 Groundwater Age in the Nossob Aquifer.....	7 - 69
Fig. 7.13a	Tritium Concentrations in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 70
Fig. 7.13b	Tritium Concentrations in the Auob Aquifer .....	7 - 70
Fig. 7.14a	Deuterium Ratios (delta D) in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 71
Fig. 7.14b	Deuterium Ratios (delta D) in the Auob Aquifer .....	7 - 71
Fig. 7.14c	Deuterium Ratios (delta D) in the Nossob Aquifer .....	7 - 71
Fig. 7.15a	Oxygen-18 ratios (delta 18 O) in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 72
Fig. 7.15b	Oxygen-18 Ratios (delta 18 O) in the Auob Aquifer .....	7 - 72
Fig. 7.15c	Oxygen-18 Ratios (delta 18 O) in the Nossob Aquifer .....	7 - 72
Fig. 7.16a	Stable Isotope Relationships in all Aquifers .....	7 - 73
Fig. 7.16b	Stable Isotope Relationships in the Unconfined Aquifer System: Kalahari, Basalt & Rietmond .....	7 - 73
Fig. 7.16c	The Stable Isotope Relationship in the Confined Auob Aquifer.....	7 - 74
Fig. 7.16d	The Stable Isotope Relationship in the Confined Nossob Aquifer .....	7 - 74

Fig. 7.16e	Deuterium Excess in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 75
Fig. 7.16f	Deuterium Excess in the Auob Aquifer .....	7 - 75
Fig. 7.16g	Deuterium Excess in the Nossob Aquifer .....	7 - 75
Fig. 7.17a	Nitrogen-15 ratios (Delta 15 N) in the Unconfined Aquifer System (Kalahari, Basalt & Rietmond).....	7 - 76
Fig. 7.17b	Nitrogen-15 ratios (Delta 15 N) in the Auob Aquifer .....	7 - 76
Fig. 7.18a	Trilinear Diagram Showing the Relative Chemical Composition of Groundwater in the Unconfined Aquifer.....	7 - 77
Fig. 7.18b	Trilinear Diagram Showing the Relative Chemical Composition and the Overall Salinity of Groundwater in the Kalahari Sediments .....	7 - 77
Fig. 7.18c	Trilinear Diagram Showing the Relative Chemical Composition and the Overall Salinity of Groundwater in the Kalkrand Basalt.....	7 - 78
Fig. 7.18d	Trilinear Diagram Showing the Relative Chemical Composition and the Overall Salinity of Groundwater in the Rietmond Formation.....	7 - 78
Fig. 7.18e	Trilinear Diagram Showing the Relative Chemical Composition and the Overall Salinity of Groundwater in the Auob Aquifer .....	7 - 79
Fig. 7.18f	Trilinear Diagram Showing the Relative Chemical Composition and the Overall Salinity of Groundwater in the Nossob Aquifer.....	7 - 79
Fig. 7.19	Diagram of SAR vs EC Indicating Suitability of Groundwater for Irrigation .....	7 - 80
Fig. 8.3-1	Isopachs of Kalahari Beds .....	8 - 7
Fig. 8.3-2	Bottom of Kalahari Beds.....	8 - 8
Fig. 8.3-3	Isopachs of Lower Riedmond Member .....	8 - 9
Fig. 8.3-4	Top of Auob Aquifer .....	8 - 10
Fig. 8.3-5	Isopachs of Auob Aquifer (Auob Member + Upper Mukorob Member) .....	8 - 11
Fig. 8.3-6	Isopachs of Lower Mukorob Member .....	8 - 12
Fig. 8.3-7	Top of Nossob Aquifer.....	8 - 13
Fig. 8.3-8	Isopachs of Nossob Aquifer .....	8 - 14
Fig. 8.3-9	Geological Columnar Sections and Hydrogeological Characteristics.....	8 - 15
Fig. 8.3-10	Location Map of Hydrogeological Cross Section .....	8 - 17
Fig. 8.3-11	Hydrogeological Cross Section-1 .....	8 - 18
Fig. 8.3-12	Hydrogeological Cross Section-2.....	8 - 19
Fig. 8.3-13	Hydrogeological Cross Section-3.....	8 - 20
Fig. 8.3-14	Hydrogeological Cross Section-4.....	8 - 21

Fig. 8.3-15	Hydrogeological Cross Section-5.....	8 - 22
Fig. 8.3-16	Hydrogeological Cross Section-6.....	8 - 23
Fig. 8.3-17	Hydrogeological Cross Section-7.....	8 - 24
Fig. 8.3-18	Hydrogeological Cross Section-8.....	8 - 25
Fig. 8.3-19	Hydrogeological Map of Southeast Kalahari Artesian Basin.....	8 - 26
Fig. 8.4-1	Elevation Survey Points .....	8 - 30
Fig. 8.4-2	Piezometric Head of Kalahari Aquifer.....	8 - 31
Fig. 8.4-3	Piezometric Head of Auob Aquifer.....	8 - 32
Fig. 8.4-4	Piezometric Head of Nossob Aquifer.....	8 - 33
Fig. 8.4-5	Piezometric Head of Kalahari Basalt .....	8 - 34
Fig. 8.4-6	Location Map of Observation Boreholes for Piezometric Head .....	8 - 35
Fig. 8.4-7	Total Precipitation during Feb. and Mar. 2000 .....	8 - 36
Fig. 8.4-8 (1)	Fluctuation of Water Level in Kalahari Aquifer at DWA's Observation Boreholes .....	8 - 37
Fig. 8.4-8 (2)	Fluctuation of Water Level in Kalahari Aquifer at DWA's Observation Boreholes .....	8 - 38
Fig. 8.4-8 (3)	Fluctuation of Water Level in Kalahari Aquifer at DWA's Observation Boreholes .....	8 - 39
Fig. 8.4-9 (1)	Fluctuation of Piezometric Head in Auob Aquifer at DWA's Observation Boreholes .....	8 - 40
Fig. 8.4-9 (2)	Fluctuation of Piezometric Head in Auob Aquifer at DWA's Observation Boreholes .....	8 - 41
Fig. 8.4-9 (3)	Fluctuation of Piezometric Head in Auob Aquifer at DWA's Observation Boreholes .....	8 - 42
Fig. 8.4-10 (1)	Fluctuation of Piezometric Head in Nossob Aquifer at DWA's Observation Boreholes .....	8 - 43
Fig. 8.4-10 (2)	Fluctuation of Piezometric Head in Nossob Aquifer at DWA's Observation Boreholes .....	8 - 44
Fig. 8.4-11 (1)	Fluctuation of Piezometric Head at JICA Test Borehole J-1 .....	8 - 45
Fig. 8.4-11 (2)	Fluctuation of Piezometric Head at JICA Test Borehole J-2 .....	8 - 46
Fig. 8.4-11 (3)	Fluctuation of Piezometric Head at JICA Test Borehole J-3 .....	8 - 47
Fig. 8.4-11 (4)	Fluctuation of Piezometric Head at JICA Test Borehole J-4 .....	8 - 48
Fig. 8.4-11 (5)	Fluctuation of Piezometric Head at JICA Test Borehole J-5 .....	8 - 49
Fig. 8.4-11 (6)	Fluctuation of Piezometric Head at JICA Test Borehole J-6 .....	8 - 50
Fig. 8.4-11 (7)	Fluctuation of Piezometric Head at JICA Test Borehole J-7 .....	8 - 51
Fig. 8.4-11 (8)	Fluctuation of Piezometric Head at JICA Test Borehole J-8 .....	8 - 52

Fig. 8.4-11 (9)	Fluctuation of Piezometric Head at JICA Test Borehole J-9 .....	8 - 53
Fig. 8.4-12 (1)	Fluctuation of Piezometric Head in Auob Aquifer at Existing Borehole .....	8 - 54
Fig. 8.4-12 (2)	Fluctuation of Piezometric Head in Nossob Aquifer at Existing Borehole .....	8 - 55
Fig. 8.5-1	TDS of Groundwater in Kalahari Aquifer.....	8 - 57
Fig. 8.5-2	TDS of Groundwater in Auob Aquifer.....	8 - 58
Fig. 8.5-3	TDS of Groundwater in Nossob Aquifer .....	8 - 59
Fig. 8.5-4	TDS of Groundwater in Kalkrand Basalt .....	8 - 60
Fig. 8.6-1	Vegetation Map of Study Area.....	8 - 74
Fig. 8.6-2	Intensity of Withdrawal from Kalahari Aquifer in 1999.....	8 - 75
Fig. 8.6-3	Intensity of Withdrawal from Auob Aquifer in 1999.....	8 - 76
Fig. 8.6-4	Intensity of Withdrawal from Nossob Aquifer.....	8 - 77
Fig. 8.6-5	Intensity of Withdrawal from Total Aquifers in 1999.....	8 - 78
Fig. 8.6-6	Recharge of Kalahari Aquifer in Ordinary Year by CDBM.....	8 - 79
Fig. 8.6-7	Recharge of Kalahari Aquifer in '99-'00 Rainy Season by CMBM .....	8 - 80
Fig. 8.6-8	Precipitation of Study Area in Ordinary Year .....	8 - 81
Fig. 8.6-9	Precipitation of Study Area during Feb. and Mar. in '99-'00 Rainy Season .....	8 - 82
Fig. 8.6-10	Evaporation Line of Groundwater in Kalahari.....	8 - 83
Fig. 8.6-11	Macro Water Balance in Ordinary Year.....	8 - 84
Fig. 8.6-12	Macro Water Balance in '99-'00 Rainy Season (Case-1 CMBM for Recharge) .....	8 - 85
Fig. 8.6-13	Macro Water Balance in '99-'00 Rainy Season (Case-2 Recovery of Water Level for Recharge) .....	8 - 86
Fig. 9.1-1	Demarcation of Bulk Water Supply System.....	9 - 1
Fig. 9.1-2	Organization Chart of NAM WATER .....	9 - 5
Fig. 9.1-3	Organization Chart of Directorate of Rural Water Supply.....	9 - 6
Fig. 9.2-1	The Structure of Septic Tank Combined with French Drain.....	9 - 8
Fig. 10.1-1	Division for Socio-economic Analysis.....	10 - 4
Fig. 10.1-2	Monitoring Area for Permission Holder .....	10 - 8
Fig. 10.1-3	Comparison Between Actual Water Use and Permitted Water Use.....	10 - 10
Fig. 10.1-4	Irrigation Water Use by Permitted Farmers (1994-1999).....	10 - 10
Fig. 11.3-1	Water Depth of Kalahari Aquifer .....	11 - 7
Fig. 11.3-2	Water Depth of Auob Aquifer.....	11 - 8
Fig. 11.3-3	Water Depth of Nossob Aquifer.....	11 - 9

Fig. 11.3-4	Depth of Auob Aquifer.....	11 - 11
Fig. 11.3-5	Depth of Nossob Aquifer .....	11 - 12
Fig. 11.3-6	Specific Yield of Kalahari Aquifer .....	11 - 13
Fig. 11.3-7	Specific Yield of Auob Aquifer .....	11 - 14
Fig. 11.3-8	Specific Yield of Nossob Aquifer .....	11 - 15
Fig. 11.3-9	Potential Evaluation of Kalahari Aquifer.....	11 - 17
Fig. 11.3-10	Potential Evaluation of Auob Aquifer.....	11 - 18
Fig. 11.3-11	Potential Evaluation of Nossob Aquifer.....	11 - 19
Fig. 12-1	Term of Permissible Limit of Groundwater Development and Conservation (modified after Shibasaki, 1972).....	12 - 52
Fig. 12-2	Schematic Diagram of Groundwater Basin Management .....	12 - 52
Fig. 12-3	General Procedure of Groundwater Simulation .....	12 - 53
Fig. 12-4	Finite Difference Grids and Finite Element Mesh (Domenico and Shwarts, 1998).....	12 - 54
Fig. 12-5	A Discretized Hypothetical Aquifer System (Harbaugh and McDonald, 1996).....	12 - 55
Fig. 12-6	Cell i,j,k and Indices for the Six Adjacent Cells (Harbaugh and Mcdonald, 1996).....	12 - 56
Fig. 12-7	Schemes of Vertical Discretization (Harbaugh and Mcdonald, 1996).....	12 - 57
Fig. 12-8	Study Area and Finite Difference Grids .....	12 - 58
Fig. 12-9	Grid System.....	12 - 59
Fig. 12-10	Estimation of Cell Size Error .....	12 - 60
Fig. 12-11	N-S Cross Section at Column 30.....	12 - 61
Fig. 12-12	E-W Cross Section at Row 30.....	12 - 62
Fig. 12-13	Distribution of Permeability of the Kalahari Aquifer.....	12 - 63
Fig. 12-14	Distribution of Permeability of the Auob Aquifer .....	12 - 64
Fig. 12-15	Distribution of Permeability of the Nossob Aquifer .....	12 - 65
Fig. 12-16	NamWater Scheme Productions.....	12 - 66
Fig. 12-17	Estimated Irrigation Uses of Permit Holders and Rainfall.....	12 - 67
Fig. 12-18	Monthly Estimated Irrigation Uses of Permit Holders and Rainfall .....	12 - 68
Fig. 12-19	Estimated Irrigation Uses of Permit Holders and Water Level of Spes Bona.....	12 - 69
Fig. 12-20	Present Groundwater Use in the Study Area.....	12 - 70
Fig. 12-21	Distribution of Groundwater Use in 1999.....	12 - 71
Fig. 12-22	Distribution of Domestic Use in 1999.....	12 - 71



Fig. 12-23	Distribution of Stock Watering Use in 1999.....	12 - 72
Fig. 12-24	Distribution of Irrigation Use in 1999.....	12 - 72
Fig. 12-25	Present Groundwater Use by Aquifer.....	12 - 73
Fig. 12-26	Domestic Use by Aquifer in 1999.....	12 - 73
Fig. 12-27	Stock Watering Use by Aquifer in 1999.....	12 - 74
Fig. 12-28	Irrigation Use by Aquifer in 1999.....	12 - 74
Fig. 12-29	Groundwater Use in Kalahari Aquifer in 1999.....	12 - 75
Fig. 12-30	Groundwater Use in Auob Aquifer in 1999.....	12 - 75
Fig. 12-31	Groundwater Use in Nossob Aquifer in 1999.....	12 - 76
Fig. 12-32	Distribution of Groundwater Use in Kalahari Aquifer in 1999.....	12 - 77
Fig. 12-33	Distribution of Groundwater Use in Auob Aquifer in 1999.....	12 - 77
Fig. 12-34	Distribution of Groundwater Use in Nossob Aquifer in 1999.....	12 - 78
Fig. 12-35	Distribution of Domestic Use in Kalahari Aquifer in 1999.....	12 - 78
Fig. 12-36	Distribution of Domestic Use in Auob Aquifer in 1999.....	12 - 79
Fig. 12-37	Distribution of Domestic Use in Nossob Aquifer in 1999.....	12 - 79
Fig. 12-38	Distribution of Stock Watering Use in Kalahari Aquifer in 1999.....	12 - 80
Fig. 12-39	Distribution of Stock Watering Use in Auob Aquifer in 1999.....	12 - 80
Fig. 12-40	Distribution of Stock Watering Use in Nossob Aquifer in 1999.....	12 - 81
Fig. 12-41	Distribution of Irrigation Use in Kalahari Aquifer in 1999.....	12 - 81
Fig. 12-42	Distribution of Irrigation Use in Auob Aquifer in 1999.....	12 - 82
Fig. 12-43	Distribution of Irrigation Use in Nossob Aquifer in 1999.....	12 - 82
Fig. 12-44	Variation of Groundwater Use in 1990-1999 by Usage.....	12 - 83
Fig. 12-45	Variation of Groundwater Use in 1990-1999 by Aquifer.....	12 - 84
Fig. 12-46	Recharge Estimation at Olifantswater (WW21815).....	12 - 85
Fig. 12-47	Calculation of Standard Water Level and Constants (C).....	12 - 86
Fig. 12-48	Observed and Calculated Groundwater Level Configuration of the Kalahari Aquifer.....	12 - 87
Fig. 12-49	Observed and Calculated Groundwater Level Configuration of the Auob Aquifer.....	12 - 87
Fig. 12-50	Observed and Calculated Groundwater Level Configuration of the Nossob Aquifer.....	12 - 88
Fig. 12-51	Plot of Simulated Versus Observed Groundwater Level.....	12 - 89
Fig. 12-52	Variation of Observed and Calculated Groundwater Level at Olifantswater.....	12 - 90
Fig. 12-53	Variation of Observed and Calculated Groundwater Level at Gomchanas.....	12 - 90

Fig. 12-54	Variation of Observed and Calculated Groundwater Level at Spes Bona .....	12 - 91
Fig. 12-55	Variation of Observed and Calculated Groundwater Level at Boomplass .....	12 - 91
Fig. 12-56	Variation of Observed and Calculated Groundwater Level at Tugela.....	12 - 92
Fig. 12-57	Variation of Observed and Calculated Groundwater Level at Gochas .....	12 - 92
Fig. 12-58	Variation of Observed and Calculated Groundwater Level at Aranós .....	12 - 93
Fig. 12-59	Variation of Observed and Calculated Groundwater Level at Aminuis .....	12 - 93
Fig. 12-60	Water Budget in 1999.....	12 - 94
Fig. 12-61	Water Budget in 2000.....	12 - 94
Fig. 12-62	Fixed Hydraulic Conductivity of Model Layer 1 (Zone Number Corresponds to that in Table 12-25) .....	12 - 95
Fig. 12-63	Fixed Hydraulic Conductivity of Model Layer 2 (Zone Number Corresponds to that in Table 12-25) .....	12 - 96
Fig. 12-64	Fixed Hydraulic Conductivity of Model Layer 3 (Zone Number Corresponds to that in Table 12-25) .....	12 - 97
Fig. 12-65	Fixed Hydraulic Conductivity of Model Layer 4 (Zone Number Corresponds to that in Table 12-25) .....	12 - 98
Fig. 12-66	Fixed Hydraulic Conductivity of Model Layer 5 (Zone Number Corresponds to that in Table 12-25) .....	12 - 99
Fig. 12-67	Fixed Hydraulic Conductivity of Model Layer 6 (Zone Numbers Corresponds to that in Table 12-25).....	12 - 100
Fig. 12-68	Fixed Specific Storage of Model Layer 4 (Zone Number Corresponds to that in Table 12-25) .....	12 - 101
Fig. 12-69	Fixed Specific Storage of Model Layer 6 (Zone Number Corresponds to that in Table 12-25) .....	12 - 102
Fig. 12-70	Fixed Recharge Zones (Zone Number Corresponds to that in Table 12-26) .....	12 - 103
Fig. 12-71	Study Cases of Future Pumping Plan .....	12 - 104
Fig. 12-72	Calculated Drawdown of the Kalahari Aquifer, Case 1 (100 years after).....	12 - 105
Fig. 12-73	Calculated Drawdown of the Kalahari Aquifer, Case 2	

	(100 years after).....	12 - 105
Fig. 12-74	Calculated Drawdown of the Kalahari Aquifer, Case 3 (100 years after).....	12 - 106
Fig. 12-75	Calculated Drawdown of the Kalahari Aquifer, Case 4 (100 years after).....	12 - 106
Fig. 12-76	Calculated Drawdown of the Kalahari Aquifer, Case 5 (100 years after).....	12 - 107
Fig. 12-77	Calculated Drawdown of the Kalahari Aquifer, Case 6 (100 years after).....	12 - 107
Fig. 12-78	Calculated Drawdown of the Auob Aquifer, Case 1 (100 years after).....	12 - 108
Fig. 12-79	Calculated Drawdown of the Auob Aquifer, Case 2 (100 years after).....	12 - 108
Fig. 12-80	Calculated Drawdown of the Auob Aquifer, Case 3 (100 years after).....	12 - 109
Fig. 12-81	Calculated Drawdown of the Auob Aquifer, Case 4 (100 years after).....	12 - 109
Fig. 12-82	Calculated Drawdown of the Auob Aquifer, Case 5 (100 years after).....	12 - 110
Fig. 12-83	Calculated Drawdown of the Auob Aquifer, Case 6 (100 years after).....	12 - 110
Fig. 12-84	Calculated Drawdown of the Nossob Aquifer, Case 1 (100 years after).....	12 - 111
Fig. 12-85	Calculated Drawdown of the Nossob Aquifer, Case 2 (100 years after).....	12 - 111
Fig. 12-86	Calculated Drawdown of the Nossob Aquifer, Case 3 (100 years after).....	12 - 112
Fig. 12-87	Calculated Drawdown of the Nossob Aquifer, Case 4 (100 years after).....	12 - 112
Fig. 12-88	Calculated Drawdown of the Nossob Aquifer, Case 5 (100 years after).....	12 - 113
Fig. 12-89	Calculated Drawdown of the Nossob Aquifer, Case 6 (100 years after).....	12 - 113
Fig. 12-90	Variation of Groundwater Level of the Kalahari and Auob Aquifer at Olifantswater.....	12 - 114
Fig. 12-91	Variation of Groundwater Level of the Kalahari and Auob	

	Aquifer at Spes Bona.....	12 - 115
Fig. 12-92	Variation of Groundwater Level of the Kalahari and Nossob Aquifer at Tugela.....	12 - 116
Fig. 12-93	Water Budget of Case-1 after 10 Years.....	12 - 117
Fig. 12-94	Water Budget of Case-2 after 10 Years.....	12 - 118
Fig. 12-95	Water Budget of Case-2 after 30 Years.....	12 - 118
Fig. 12-96	Water Budget of Case-3 after 10 Years.....	12 - 119
Fig. 12-97	Water Budget of Case-4 after 30 Years.....	12 - 119
Fig. 12-98	Water Budget of Case-4 after 10 Years.....	12 - 120
Fig. 12-99	Water Budget of Case-4 after 30 Years.....	12 - 120
Fig. 12-100	Water Budget of Case-5 after 10 Years.....	12 - 121
Fig. 12-101	Water Budget of Case-5 after 30 Years.....	12 - 121
Fig. 12-102	Water Budget of Case-6 after 10 Years.....	12 - 122
Fig. 12-103	Water Budget of Case-6 after 30 Years.....	12 - 122
Fig. 13.1-1	Annual Growth Rate of Gross Domestic Product by Sector .....	13 - 23
Fig. 13.2-1	Livestock Population in the Districts Concerned .....	13 - 35
Fig. 13.2-2	Temperature and Rainfall in Stampriet .....	13 - 36
Fig. 13.2-3	Cropping Pattern .....	13 - 37
Fig. 15.2.1	Actual Irrigation Use and Permitted Water Use.....	15 - 8
Fig. 15.2-2	Comparison Between Irrigation Use and Permitted Water Use.....	15 - 13

## ABBREVIATIONS

ASL	: Above Sea Level
AGL	: Above Ground Level
BGL	: Below Ground Level
CMBM	; Chloride Mass Balance Method
CSAMT	: Controlled Source Audio Magnet Telluric
DO	: Dissolved Oxygen
DRWS	: Directorate of Rural Water Supply
DVS	: Directorate of Veterinary Services
DWA	: Department of Water Affairs
EC	: Electric Conductivity
GDP	: Gross Domestic Product
GPS	: Global Positioning System
GVA	: Gross Value Added
IAEA	; International Atomic Energy Agency
IEE	; Initial Environment Evaluation
IMF	: International Monetary Fund
JICA	: Japan International Cooperation Agency
MAWRD	: Ministry of Agriculture, Water and Rural development
NamWater	: Namibia Water Corporation
SABS	: South African Bureau of Standard
T	: Temperature
TDEM	; Time Domain Electric-Magnetic
TDS	: Total Dissolved Solids
TEM	: Transient Electro Magnetic
USAID	: United States Agency for International Development
USGS	: United States Geological Survey

## CHAPTER 1 INTRODUCTION

### 1.1 Background of the Study

The Southeast Kalahari (Stamriet) Artesian Basin (hereinafter referred to as “the Southeast Kalahari Artesian Basin” is situated in the southeastern part of Namibia. The Southeast Kalahari Artesian Basin is the largest groundwater basin in the country, which extends eastwards to Botswana and South Africa. Its area is approximately 71,000km<sup>2</sup>. The basin is almost entirely overlain by the Kalahari Beds.

Groundwater from the basin is supplied to both commercial and communal farmers for their domestic, livestock and irrigation purposes. It is also supplied to the towns of Stamriet, Gochas, Aranos and Leonardville by the bulk water supply system of NamWater.

Groundwater abstraction within the Southeast Kalahari Artesian Basin has been controlled by regulations promulgated in terms of the Water Act. Extensive groundwater abstraction by commercial farmers occurs in the northern and central parts of the basin. Groundwater levels have been declining continuously since 1980 according to some monitoring wells that were installed during 1978.

Consequently, a Hydrocensus was carried out by the Department of Water Affairs (DWA) during 1986 to 1988 in order to define the impact due to abstraction of the groundwater. Since then, no further work has been done, although, groundwater use has steadily increased to nearly double that of 1988.

In order to manage the excessive abstraction, DWA needs to understand the nature of entire aquifer system. Accordingly, the Government of Namibia requested the Government of Japan to carry out an investigation of the groundwater flow and recharge mechanism of the Southeast Kalahari Artesian Basin and to formulate a groundwater management plan for sustainable groundwater usage.

### 1.2 Objectives of the Study

The objectives of the study are:

- (1) To investigate the groundwater flow regime and recharge mechanism within the Southeast Kalahari Artesian Basin;
- (2) To evaluate the groundwater potential to support sustainable development within the Southeast Kalahari Artesian Basin;
- (3) To formulate a groundwater management plan within the Southeast Kalahari

Artesian Basin;

- (4) To achieve technology transfer to counterpart personnel during the course of the study.

### 1.3 Study Area

The study area covers the Southeast Kalahari Artesian Basin (approximately 71,000km<sup>2</sup>) as shown in the figure at the beginning of the report.

### 1.4 Implementation of Study

The Department of Water Affairs (DWA) of the Ministry of Agriculture, Water and Rural Development (MAWRD) was assigned as the counterpart organization by the Government of Namibia, while the Japan International Cooperation Agency (JICA) was assigned as the official agency responsible for the implementation of the technical cooperation program of the Government of Japan.

The study was conducted by the Japanese study team, comprised members of Pacific Consultants International and Sanyu Consultants Inc., officially retained by JICA for the study, and the counterpart staff provided by the DWA.

The total schedule of the study is shown in Table 1.4-1.

The members involved in the study are shown in Table 1.4-2.

Table 1.4-1 Total Schedule of the Study

Year Month	2000												2001												2002																													
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar																																
Work in Namibia	1 <sup>st</sup> Field Survey												4 <sup>th</sup> Field Survey												5 <sup>th</sup> Field Survey																													
	[4] Submission and discussion of IC/R [5] Existing data collection, review and analysis [6] Landsat imagery interpretation [7] Aerial photo Interpretation [8] Topographical, geological and hydrogeological investigation [9] Existing borehole survey [10] Water usage [11] Preliminary environmental survey [12] Geophysical survey [13] Formulation of study plan for 2nd and 3rd field survey [14] Preparation and discussion of P/R(1)	2 <sup>nd</sup> Field Survey												3 <sup>rd</sup> Field Survey												Discussion of DF/R																												
Work in Japan	Preparation of the Study												1 <sup>st</sup> Work In Japan												2 <sup>nd</sup> Work In Japan												3 <sup>rd</sup> Work In Japan			4 <sup>th</sup> Work In Japan														
	[1] Collection, review and analysis of related data and data [2] Examination of study approach and methodology [3] Preparation of IC/R	[15] Test borehole drilling, borehole logging and pumping test [16] Observation of groundwater levels [17] Water quality analyses [18] Renewal of database of boreholes [19] Present water usage and water consumption forecast												[20] Test Borehole drilling, borehole logging and pumping test [21] Observation of groundwater levels [22] Water quality analysis [23] Elevation survey for existing boreholes (DGPS) [24] Survey on meteorology and hydrology [25] Preliminary hydrogeological analyses [26] Groundwater modeling(1) [27] Preparation and discussion of P/R(2)												[28] Hydrogeological analysis [29] Water balance analysis [30] Groundwater modeling (2)												[31] Preliminary groundwater simulation [32] Preliminary evaluation of the groundwater potential for sustainable usage [33] Preparation of IT/R												[34] Discussion of IT/R [35] Groundwater simulation potential for sustainable usage [36] Formulation of groundwater management plan			[37] Formulation of groundwater management plan [38] Preparation of DF/R [39] Discussion of DF/R [40] Preparation of F/R	
Study Stage	Phase I : Data Collecting and Analysis												Phase II : Groundwater Field Survey												Phase III : Analysis and Evaluation																													
Report	Inception Report												Progress Report (1)												Progress Report (2)												Interim Report			Draft Final Report			Final Report											

<Notes> [ ] : Completed. [ ] : Inception Report P/R: Progress Report IT/R: Interim Report DF/R: Draft Final Report F/R: Final Report



Table 1.4-2 Member List

Name	Assignment
< Study Team of JICA >	
Mr. Yasumasa YAMASAKI	Team Leader/Groundwater Management Planner
Mr. Norifumi YAMAMOTO	Hydrogeologist (A)
Dr. Mahbub A. K. REZA	Hydrologist/Water Balance Expert
Dr. Gideon TREDoux	Water Quality/Environmental Specialist
Mr. Yuichi HATA	Hydrogeologist (B)/Drilling Expert
Mr. Katsuhiko FUJISAKI	Groundwater Simulation Expert
Mr. Kensuke IRIYA	Socio-Economist
Mr. Hiroyoshi YAMADA	Coordinator
<DWA Staff>	
	<Title>
Mr. Piet HEYNS	Director: Resource Management
Mr. Greg CHRISTELIS	Deputy Director: Geohydrology
Mr. Guido Van LANGENHOVE	Deputy Director: Hydrology
Mr. Dudley BIGGS	Deputy Director: Planning
Mr. Don LOUW	Principal Hydrogeologist
Mr. Harmut STRUB	Senior Hydrologist
Mr. Piet LIEBENBERG	(Irrigation Division, Department of Agriculture)
Mr. Alex KATJUONGUA	Chief Technical Assistant
Ms. Theopauline NGULA	Technical Assistant