JAPAN INTERNATIONAL COOPERATION AGENCY
THE GOVERNMENT OF THE KINGDOM OF MOROCCO

FEASIBILITY STUDY
ON WATER RESOURCES DEVELOPMENT
IN RURAL AREA
INTHE KINGDOM OF MOROCCO

FINAL REPORT

VOLUME III

SUPPORTING REPORT (1)

BASIC STUDY

AUGUST, 2001

JOINT VENTURE OF
NIPPON KOEI CO., LTD. AND
NIPPON GIKEN INC.

LIST OF FINAL REPORT VOLUMES

Volume I: Executive Summary

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Volume VII: Data Book

Data Book AR:	***Aero-Photo and Ground Survey***
Data Book GC:	***Geology and Construction Materials***
Data Book HY:	***Hydrology***
Data Book SO:	***Soil Survey***
Data Book NE:	***Natural Environment***
Data Book SE:	***Social Environment***
Data Book EA:	***Economic Analysis***

The cost estimate is based on the price level and exchange rate of April 2000. The exchange rate is:
US$ 1.0 = Moroccan Dirham (DH) 10.68 and
Japanese Yen 100.0 = Moroccan Dirham (DH) 9.90

PREFACE

In response to a request from the Government of the Kingdom of Morocco, the Government of Japan decided to conduct the Feasibility Study on Water Resources Development in Rural Area in the Kingdom of Morocco and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team headed by Mr. M. Kawashima of NIPPON KOEI Co., LTD (and consists of NIPPON KOEI Co., LTD. and NIPPON GIKEN INC.) to the Kingdom of Morocco, three times between December 1999 and August 2001. In addition, JICA set up an advisory committee headed by Mr. Hayao Adachi, Senior Advisor of JICA between December 1999 and August 2001 (and by Dr. Akira Niwa, Senior Advisor of JICA between April 2001.and July 2001), which examined the study from specialist and technical points of view.

The team held discussions with the officials concerned of the Government of the Kingdom of Morocco and conducted field surveys at the study areas. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of this project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of the Kingdom of Morocco for their close cooperation extended to the Study.

August 2001

Kunihiko Saito
President
Japan International Cooperation Agency

Mr. Kunihiko Saito
President, Japan International Cooperation Agency
Tokyo, Japan

LETTER OF TRANSMITTAL

It is with great pleasure that we submit to you the Final Report of the "Feasibility Study on Water Resources Development in Rural Area in the Kingdom of Morocco".

The Study has been made to formulate the water resources development plans for the 25 medium-scale dam projects proposed by the Ministry of Equipment (MOE) and select the 4 priority projects (Phase I Basic Study), and to conduct a feasibility study of the 4 priority projects based on the water resources development plans (Phase II Feasibility Study).

The Report consists of Part I and Part II. Part I presents the results of the Basic Study and Part II incorporates the results of the Feasibility Study.

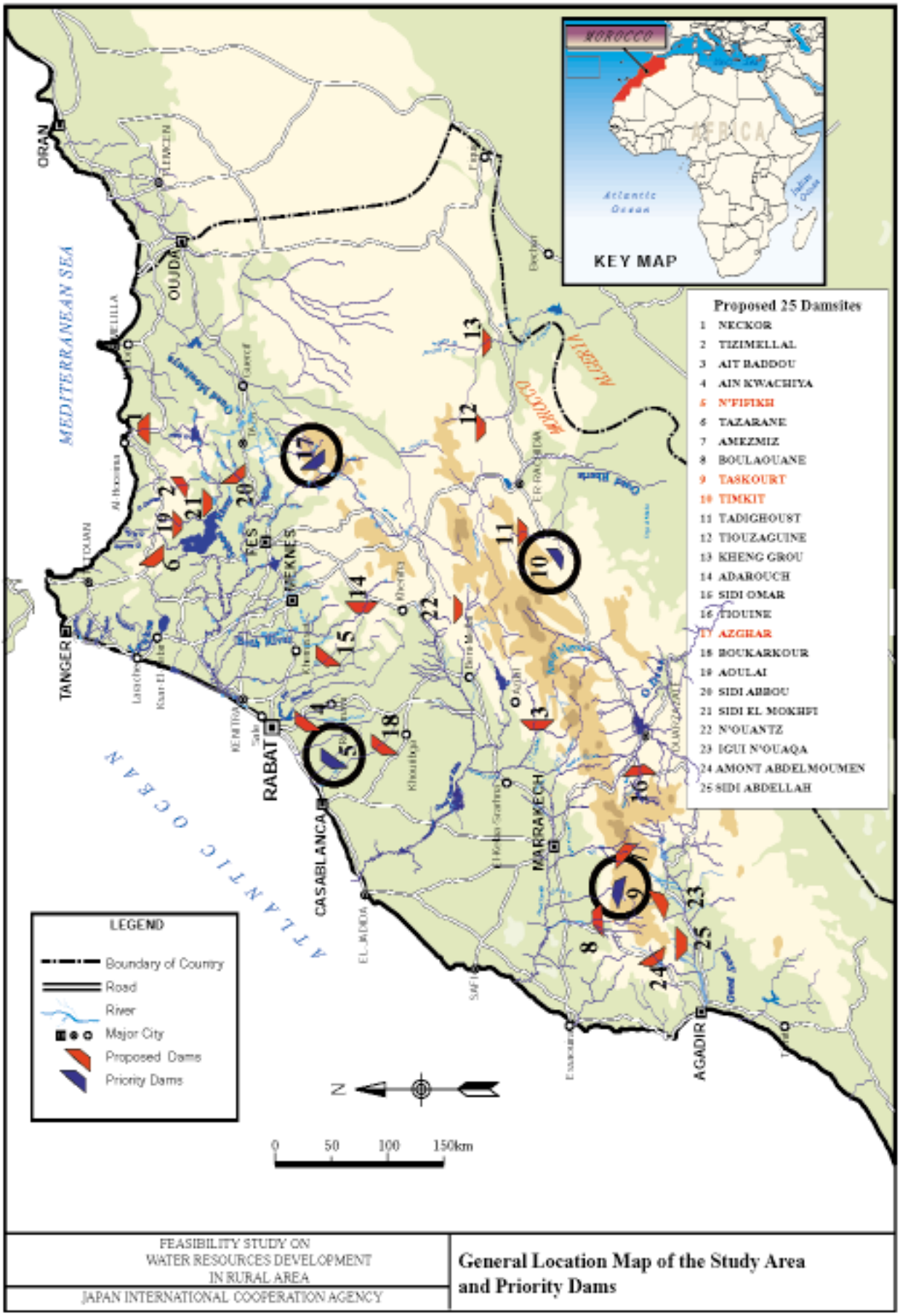
We hope that this report will be helpful for water resources development in rural areas in the Kingdom of Morocco.

We wish to express our deep appreciation and gratitude to the personnel concerned of your Agency, JICA Morocco Office, the Embassy of Japan in Morocco, MOE and the other authorities concerned of the Government of the Kingdom of Morocco for the courtesies and cooperation extended to us during our Study.

Very truly yours,

August 2001

Motoyoshi Kawashima
Team Leader for the Feasibility Study
on Water Resources Development in Rural Area
in the Kingdom of Morocco



FEASIBILITY STUDY ON
WATER RESOURCES DEVELOPMENT
IN RURAL AREA

JAPAN INTERNATIONAL COOPERATION AGENCY

General Location Map of the Study Area and Priority Dams

ABBREVIATIONS

Abbreviations	ENGLISH	FRENCH
AEP	Potable Water Supply	**A**pprovisionnement en **E**au **P**otable
APD	Detailed Study	**A**vant **P**rojet **D**étaillé
AUEA	Association of Agricultural Water Users	**A**ssociation des **U**sagers de l'**E**au **A**gricole
BAD	African Bank for Development	**B**anque **A**fricaine de **D**éveloppement
BM	World Bank	**B**anque **M**ondiale
CAM	Agricultural Cooperative of Morocco	**C**oopérative **A**gricole du **M**aroc
CDA	Agricultural DevelopmentCenter	**C**entres de **D**éveloppment **A**gricole
CERED	Center for demographic Research and Studies	**C**entre des études et de **R**echerche **D**émographiques
CLCA	Local Fund for Agricultural Credit	**C**aisse **L**ocale de **C**rédit **A**gricole
CMV	Development Center	**C**entre de **M**ise en **V**aleur
CNCA	National Fund for Agricultural Credit	**C**aisse **N**ationale de **C**rédit **A**gricole
CNE	National Council of Environment	Le **C**onseil **N**ational de l'**E**nvironnement
CSEC	Superior Council for Water and Climate	**C**onseil **S**upérieur de l'**E**au et du **C**limat
DAR	Directorate of Rural Affairs	**D**irection des **A**ffaires **R**urales
DCL	Directorate of Local Collectivities	**D**irection des **C**ollectivités **L**ocales
DCRF	Directorate of Forest Resources Conservation	**D**irection de la **C**onservation des **R**essources **F**orestières
DDF	Directorate of Forest Development	**D**irection de **D**éveloppement **F**orestière
DE	Directorate of Operation	**D**irection des **E**conomiques
DELM	Directorate of Epidemology and Abatement of Disease	**D**irection d'**E**pidemologie et de **L**utte Contre les **M**aladies
DEP	Directorate of Design and Planning	Direction de Planification et des Plans
DEPR	Division of Potable Rural Water Supply	**D**ivision d'Alimentation en **E**au Potable en Milieu **R**ural
DERD	Decentralized Regional Directorate	**D**irection de l'**E**nseignement, de la Recherche et de Développement Rural
DF	Directorate of Finance	Direction des Finances
DGCL	General Directorate of Local Communities	**D**irection **G**énérale des **C**ollectivités **L**ocales
DGH	Directorate General of Hydraulics	**D**irection **G**énérale de l'**H**ydraulique
DH	**D**irham	**D**irham
DIEC	**D**ivision of **I**nformation, **E**ducation and **C**ommunication	**D**ivision d'**I**nformation, **E**ducation et **C**ommunication
DP	Provincial Directorate	**D**irection **P**rovinciale

Abbreviations	ENGLISH	FRENCH
DPA	Provincial Directorate of Agriculture	**D**irection **P**rovinciale d' **A**griculture
DPA	Provincial Directorate of Animal	**D**irection **P**rovinicials de l' **A**nimale
DPTP	Provincial Directorate of Public Works	**D**irection **P**rovinciale des **T**ravaux Publiques
DPV	Directorate of Vegetable Production	**D**irection de la **P**roduction **V**égétale
DRD	**D**ecentralized **R**egional **D**irectorate	**D**irection **R**égionale **D**écentralisée
DT	Division of Works	**D**ivision du **T**ravail
EIRR	**E**conomic **I**nternal **R**ate of **R**eturn	
EMP	**E**nvironmental Management **P**lan	Plan de Gestion Environnementale
FERTIMA	Moroccan Company of Fertilizers	**S**ociété **M**arocaine de **F**ertilisation
FV	Training Visit	**F**ormation **V**isite
GH	Large Hydraulic	**G**rande **H**ydraulique
GPD	**G**ross **D**omestic **P**roduct	Produit National Brut
HCWC	**H**igh **C**ouncil of Water and **C**limate	Conseil Superieur de l'eau et du Climat
IBRD	**I**nternational **B**ank for **R**econstruction and **D**evelopment	Banque Internationale pour la Reconstruction et le Développement
INH	National Institute of Hygiene	**I**nstitut **N**ationale de l'**H**ygiène
JBIC	**J**apan **B**ank for **I**nternational **C**ooperation	Banque Japon de Coopération Internationale
JICA	**J**apan **I**nternational **C**ooperation **A**gency	Agence Japonaise pour la Coopération Internationale
MADRPM	Ministry of Agriculture, Rural Development and Maritime Fishing	**M**inistère de l'**A**griculture du **D**éveloppement **R**ural et des **P**êches **M**aritimes
MCEF	Ministry In Charge of Water and Forests	**M**inistère **C**hargé des **E**aux et **F**orêts
MI	**M**inistry of **I**nterior	**M**inistère de l'**I**ntérieur
MOA	**M**inistry of **A**griculture, Rural Development and Fishery	Ministère de l'Agriculture du développement Rural et des Pêches maritimes
MOE	**M**inistry of **E**quipment	Ministère de l'Equipement
MOI	**M**inistry of **I**nterior	Ministère de l'Intérieur
MPW	**M**inistry of **P**ublic **W**orks	Ministère des travaux Publics
MSL	**M**ean **S**ea **L**evel	Niveau Moyen de La mer
MSP	Ministry of Public Health	**M**inistère de la **S**anté **P**ublique
NG	**N**atural **G**round	Sol Naturel
NPV	**N**et **P**resent **V**alue	Valeur Nette Actuelle
OECF	**O**verseas **E**conomic **C**ooperation **F**und (now JBIC)	Fond de Coopération Economique Etrangère
OMM	**O**peration, **M**aintenance and **M**anagement	Opérations de gestion et de maintenance
ONE	National Office of Electricity	**O**ffice **N**ational de l'**E**lectricité
ONEP	National Office of Potable Water	**O**ffice **N**ational de l'**E**au **P**otable

Abbreviations	ENGLISH	FRENCH
ONICL	Inter professional National Office of Cereals and Leguminous	**O**ffice **N**ational Inter professionnel des **C**éréales et **L**égumineuses
ORMVA	Regional Office for Agricultural Development	**O**ffice **R**égional de la **M**ise en **V**aleur **A**gricole
PAGER	Program of Grouped Supply of Rural Water	**P**rogramme d'**A**pprovisionnement **G**roupé des **E**aux **R**urales
PAGI	Program of Large Irrigation Improvement	**P**rogramme d'**A**mélioration de la **G**rande **I**rrigation
PMH	Small and Medium-ScaleHydraulic	**P**etit et **M**oyenne **H**yraulique
PNI	National Program of Irrigation	**P**rogramme **N**ational de l'**I**rrigation
PRV	Extension and Research Project	**P**rojet de **R**echerche et de **V**ulgarisation
PSDA	Agricultural Development and Support Project	**P**rojet de **S**upport et de **D**éveloppement **A**gricole
SE	Water Service at the Provincial Directorate of Public Works	**S**ervice **E**au à la Direction provinciale de l'Equipement
SH	Section of Hydology	**S**ervice d'**H**ydraulogie
SIBE	Site of Biological and Ecological Interest	**S**ite d'**I**ntérêt **B**iologique et **E**cologique
SMN	Service of National Meteorology	**S**ervice de la **M**étéorologie **N**ationale
SONACOS	National Company of Seed Trade	**S**ociété **N**ationale de **C**ommercialisation de **S**emences
UNCAM	National Union of Cooperatives of Morocco	**U**nion **N**ationale de **C**oopératives du **M**aroc
UNDP	**U**nited **N**ations **D**evelopment **P**rogram	Programme des Nations Unies pour le Développement (PNUD)

Conversion Factors

	Metric to Imperial			Imperial to Metric		
Length	1 cm	=	0.394 inch	1 inch	=	2.54 cm
	1 m	=	3.28 feet	1 feet	=	30.48 cm
	1 km	=	0.621 mile	1 mile	=	1.609 km
Area	1 m^2	=	10.76 sq.ft	1 sq.ft	=	0.0929 m^2
	1 ha	=	2.471 acre	1 acre	=	0.4047 ha
	1 km^2	=	0.386 sq.mile	1 sq.mile	=	2.59km^2
Volume	1 lit	=	0.22 gal (imp)	1 gal(imp)	=	4.55 lit
	1 m^3	=	35.3 cu.ft	1 cu.ft	=	28.33 lit
	1 MCM	=	811 acre-ft	1 acre-ft	=	1,233.5 m^3
Weight	1 kg	=	2.20 lb	1 lb	=	0.4536 kg
	1 ton	=	0.984 long ton	1 long ton	=	1.016 ton
Derived	1 m^3/s	=	35.3 cusec	1 cusec	=	0.0283 m^3/s
Measures	1 ton/ha	=	891 lb/acre	1 lb/acre	=	1.12 kg/ha
	1 m^3/s	=	19.0 mgd	1 mgd	=	0.0529 m^3/s
Temperature	°C	=	(^{o}F-32)x5/9	^{o}F	=	1.8x°C+32
Local	1 lit	=	0.22 gantang	1 gantang	=	4.55 lit
Measures	1 kg	=	1.65 kati	1 kati	=	0.606 kg
	1 ton	=	16.5 pikul	1 pikul	=	60.6 kg

Feasibility Study on Water Resources Development in
Rural Area in
the Kingdom of Morocco
Final Report
Volume III Supporting Report (1)
Basic Study

Supporting Report I Geology

FEASIBILITY STUDY
ON
WATER RESOURCES DEVELOPMENT
IN
RURAL AREA
IN
THE KINGDOM OF MOROCCO

FINAL REPORT

VOLUME III
SUPPORTING REPORT (1)
BASIC STUDY

SUPPORTING REPORT I
GEOLOGY

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SUPPORTING REPORT I

GEOLOGY

I1 Physiography and Geology of Morocco

I1.1 Physiography

Morocco is located at the northwestern end of African Continent facing to Mediterranean Sea and Atlantic Ocean, and having Eastern national border with Algeria and Southern border with Mauritania passing through the area of Western Sahara. The distance from Spain is only 14 km where Gibraltar is in between. The country area is 710,850km^2.

The physiography of Morocco is characterized largely by four mountain chains of "Rif", "Moyen Atlas", "Haute Atlas" and "Anti Atlas". Two other areas are extending among them, one of which is Morocco Central Area in the western side surrounded by Rif, Moyen Atlas, Haute Atlas and Atlantic Ocean, and another is Olanaise Plateau in the eastern limited by Moyen Atlas and Haute Atlas extending towards Mediterranean Sea. Sahara Desert is vastly situating in the southern side of Anti Atlas.

Rif Mountains, that is one of Alps Orogenic Mountains, line up as the island arc representing J. Lechchab (EL. 2,170m) as the highest peak in the northeastern, and M. Tidiquin (2,456m), A. Abecher (2008m) in the central and the eastern. Its northern slope is generally facing to Mediterranean Sea as rocky coast, and rivers are pouring themselves directly into that. The southern slope is gradually going down to Prérif-hillock area and all rivers are confluent to Ouergha River.

These mountains and hillock area are limited its southern side by South Rif Depression forming Saïs heights and Rharb plain and Ouergha River confluent to Sebou River.

While, the Atlas represented by Haute Atlas in the southern area separates the Moyen Atlas from the mid-part towards the northeastern.

Haute Atlas extends 800 km length in the direction of east and west with 40～80 km width having their peaks around 4,000 m. The highest peak is J.Toubkal (4,165m) in the western part, J.Mgoun (4,071m) in the central part, and J.Ayachi (3,751m) in the eastern part.

In the case of Moyen Atlas, it extends about 200 km length towards the northeastern after separating from Haut Atlas with some tenth kilometers width.

Its peaks range from 2000 to 3000 m, and the highest is Adar Bou Nasseur (3,326m) situating around the northeastern end.

Morocco Central Area extends to the south from South Rif Depression, so called "Méséta Central Marocain" subdivided into five provinces such as "Méséta Cotiere", "Morocco Méséta", "Bahia-Tadla Syncline", "Jbilet", and "Magador-Haouz Syncline".

Méséta Cotiere is the side of the Atlantic Ocean having some level of terraces (besides alluvial coastal plain, around three terraces with the border of elevation around 200 m and 500 m). Morocco Méséta is inlands' mountains or plateaus (elevation about from 500 to 1,000 m). Massif Central and Rehamna Mountain lie on these two areas. Furthermore in the southern side of Morocco Méséta, "Plateaux de Phosphats" is widely extending.

In further southern side, Jbilet Small Mountains extend east and west with two Synclinal areas along both sides. Their elevation is usually lower than 500 m forming wide alluvial basins along Oum er Rbia River and Tensift River supplied also from Morocco Méséta and Atlas.

It is characteristically observed that terrace-like plain lands are situating in Méséta Cotiere, Morocco Méséta and Rharb Plain.

The highest plain land is formed by marine transgression at the time of Upper Cretaceous to Eocene. Middle to lower plain lands were formed at Oligocene to Miocene. Ancient Rharb River was filled by Molasses transgression at Tortonian, and upheavals at the time from Miocene via Pliocene to Lower to Middle Villafranchian and regression from South Rif Depression at Upper Pliocene resulting sedimentation accumulation along the coast of Atlantic Ocean (Moghrébien). Inland of Méséta, very wide glacis terraces were formed along river course. Upheavals were going on reaching 60 m near the coast and 300 m around Massif Central, and then it can be observed around 6 levels of terraces.

Moulouya Olanaise Méséta (Haute-Moulouya and Hauts-Plateaux) is the highland of elevation more than 1,000 m between Haute Atlas and Moyen Atlas. Rivers in this area are generally pouring themselves into Moulouya River Alluvial area, which is flowing along the periphery of Moyen Atlas and pouring itself into Mediterranean Sea.

Along the southern periphery of Haute Atlas, Agadir Basin of Souss River facing to the coast of Atlantic Ocean, Ouarzazate Depression, and Rheris-Ziz River basin around Errachidia are extending, and then Anti Atlas and the Western Africa Craton forming Sahara Deserts is vastly extending.

Anti Atlas forms the periphery of Western Africa Craton orienting parallel with Haute Atlas keeping distance around 100 km, and having their peaks around 2,500 m except the case of the highest peak J.Siroua (3,304m) that is located away around 50 km SSE from J.Toubkal.

This general situation is shown in Figure I1.1.1.

I1.2 Geology

Structurally, geology around Morocco is largely divided into the following four regions.

(1) Northern Morocco (Mediterranean Morocco)
: Rif Province (Alps Type Orogenic Zone and Nappe)
Orogenic Zone (Rif Mountains): Paleozoic to Tertiary (up to Miocene)
Nappe and Olistostrome: Miocene

(2) Central Morocco (Africa Morocco 1)
: Méséta Province & Atlas Mountains Province
German Type Orogenic Zone (Paleozoic and Mesozoic)

(3) Southern Morocco (Africa Morocco 2)
: Anti-Atlas Province (peri-cratonic)
Precambrian to Paleozoic Folding Zone (Anti-Atlas Mountains)

(4) Sahara Structural Plain (Western Africa Craton)
: Precambrian Craton (non-folded or slightly folded) (Reguibat Shield)
and Upper Infracambrian to Paleozoic (Tindouf Basin)

Comparing to Physiographical Provinces: Rif Province ＝Rif, & Prérif; Méséta Province ＝Morocco Méséta, Méséta Cotiére, Bahia-Tadla Syncline, Jbilet, & Magador-Haouz Syncline; Atlas Mountains Province ＝Moyen Atlas, Haute Atlas, & Moulouya-Olanaise Méséta; Anti-Atlas Province ＝Anti-Atlas.

Rif Province of Northern Morocco is the area of the islands arc to the southwards from Rif Mountains to Prérif Hillocks, where consists of the overthrust and the metamorphosed mass with Ophiolite. Basement rocks are of the orthogeosynclinal deposits of Hercynian to Caledonian, or partly of Precambrian (Tethysian Sea).

In the northern part of Rif rises Central Range by the Geoanticlinal Zone which separates the Province into the outside and the inside (Mediterranean side), where the former is called “Infra” and the latter “Ultra”. In this sub-province, Limestone–Dolomite of Triassic and Lias is ranging as skyscraper and the zones of Paleozoic group, Crystalline Schist, or partly Ultarabasics are extending.

Central Rif is composed of the zone of Schist and Marl, which is so called “Rif Facies”, and divided into the following two zones.

1) Ultra-Rif Zone

2) Intrarif Zone and its outside periphery called Mesorif Zone

Ultra-Rif Zone is so called the “Flysh Nappe” composed of Flysh and Pelagic Sediments Facies napped from Mediterranean Sea side, while the second zones are composed of autochtonous rocks extending in the outside of the zone 1. Generally, Intrarif is so called the “Fenster” of Cretaceous and Mesorif is of Jurassic to Miocene.

Southern Rif is hillock area composed mainly of Mudstone and/or Marl undulating gently, where is so called “Prérif Zone”. The inside zone of Prérif (Sofs Line) is composed of autochtonous Jurassic and Cretaceous, and the outside zone is of allochtonous Nappe until Lower to Middle Miocene pushed out from Intrarif Zone.

Southern periphery of Rif is called “South Rif Depression (Sillon de Sud Rif)” extending Saïs Tableland and Gharb Plain, where are the zone of subsiding and the Alluviums deposited thick.

In the eastern side of Rif, some volcanoes of Rhyolite and Trachyandesite are scattered.

Méséta and Atlas Mountains Provinces of Central Morocco (Africa Morocco 1) are the Caledonian to Hercynian geosynclinal zone of Paleozoic and Mesozoic with Flysh deposits strongly folded and garanitizated (Granite dyke is relatively few).

The Atlantic coast side of Méséta Cotiére and Morocco Méséta Provinces is composed of Triassic, the northern side towards Rif is of Lower to Middle Jurassic, and the southern side of the border with Haut Atlas is of Upper Jurassic and Lower Cretaceous. The southern part of Morocco Méséta is called “Phosphate Plateau (Plateau des phosphates)” of Upper Cretaceous to Eocene. Basement rocks of Paleozoic partly granitized are going to lie under the Plateau des phosphates towards the Southwest, and later appearing again as semi-dome Rehamna Massif and small mountains ranging East-West with peak elevation around 1000 m as Jbilet Massif proceeding to the south. Towards northeastern side, they underlie through Moyen Atlas Causse and appear again as the peak of Tazekka. Geology of Méséta Province is influenced by Atlantic Ocean and subdivided as the followings structurally as described above:

1) Massif Central
2) Rehamna Massif and Cotiére Méséta
3) Jbilet Small Mountains of the Northwestern side of Haouz

In Atlas Mountains Province, Haute Atlas is divided structurally as the following three.

1) Ancient Massif of Western Haut Atlas (called Marrakech' Atlas)
   Precambrian and partly granitized Paleozoic

2) Central Haute Atlas
   Very thick marine deposits of Lower to Middle Jurassic; Limestone is dominant; Covered by the geosyncline of Cretaceous and the geoanticline of Triassic.

3) Eastern Haute Atlas is basically same as the Central Haute Atlas, but the thickness of Triassic is much thinner.

Central and Eastern Atlas is also called "Calcareous Haute Atlas (Haute Atlas Calcaire)" together.

The Ocean side of Haute Atlas from Arghana Triassic gorge is almost composed of Limestone where geological series belong to the Atlantic.

Moyen Atlas is the mountain of Triassic to Jurassic so that the hydrogeologic condition in this area is quite complicated by karsts. Moulouya River is mainly recharched from Moyen Atlas.

Moulouya-Olanaise Méséta consists of structural plain, highland and hills where can be separated Haute-Moulouya in the mountainside and Hauts-Plateaux in the eastern side. Haut-Moulouya is on the basements of Granites and the undifferentiated metamorphosed rocks, while the basements of Hauts-Plateaux is rather free from metamorphism and resemble to those of Anti-Atlas and Méséta. However, Mesozoic and Tertiary are much more developed.

Atlas Mountains Province is limited south by the "South Atlasic Fault (l'Accident Sud Atlasique)". Then along this, some depressed areas (called "Sillon Préafricain") are developed and Alluviums extend in this area. These Faults may be compatible with the Hercynian Lateral Fault.

Southern Morocco (Africa Morocco 2), Anti-Atlas Province consists of Paleozoic and Infracambrian, which were deformed by Hercynian Orogeny. As a result, some middle scale of folding and fault develops and vertical schistosity is accompanied.

Sahara Structural Plain extending further southwards is the area of Western Africa Craton, as proceeding to south “Appalachia Relief Zone” (zone de relief), Cretaceous Kem-Kem Hamada, Tertiary to Quaternary Daoura/Dra Hamada, and Tindouf Bain, etc.

Geological map of Morocco is shown in Figure I1.2.1

I2 General Physiographical & Geological Situation of Respective Dam Sites

Six sites of the Zone I area except Azghar and Adarouch, that is 1,Neckor, 2,Tizimellal, 6,Tazarane, 19,Aouli, 21,Sidi-el-Mokhi and 20,Sidi-Abbou, situate physiographically on Northern Morocco Rif Mountain Area where geologically it is composed of Rif Province.

Among of them, the former 5 sites are located in the zone of Intra-Rif where two sites (1,Neckor and 2,Tizimellal) belong to in the Ketama Unit, and three sites (6,Tazarane, 19,Aouli, and 21,Sidi-el-Mokhi) are in the Tanger Unit, though the Irrigation area of 21,Sidi-el-Mokhi is mainly in the zone of Meso-Rif.

The geology of Ketama Unit consists of hard Flysh facies mainly of Quartzite and Psammitic Schist of Lower Cretaceous where the western side is schistose weakly and show simple structure, on the other hand the eastern side is schistose strongly accompanied with a lot of folding structure. Neckor and Tizimellal are in the eastern side. The area is generally mountainous rising steeply and some of their peaks are over 2000 meters above MSL.

The geology of Tanger Unit consists mainly of Upper Cretaceous where is generally composed of relatively soft and simple structure of Pelitic Schist, Marl, and marly black Limestone. Topography in this area is mountainous to hillock, looks generally gentle impression due to the rounded shape of mountain peak, but it tends that their slope is going to be steep as proceeding to the bottom of valley. The shape of river valley is sometimes very narrow gorge and sometimes very wide.

Sidi-Abbou dam site belongs to the inner zone of Pre-Rif consisting mainly of Jurassic Limestone. While in both bank side of reservoir area, marl distributes mainly. The command area is in the outer zone of Pre-Rif composed of partly saline formations of Eocene to Miocene. Topography is generally gentle hillock area, however the area outcropping Limestone only forms the very steep mountains and/or gorges.

The dam site of 17,Azghar in Zone I is located geologically in the Moyen Atlas Province composed of the alternation of black Limestone and marly Limestone of Lower to Middle Jurassic.

The location is in relatively gentle hillock range area of the periphery of Moyen Atlas.

14,Adarouch dam site of Zone I and the dam sites in the Zone II are located geologically in Mèsèta Province where is composed of mainly Hercynian Paleozoic formations situated as Morocco Central Massif. Southwestern side of the Massif is covered by Tertiary called as “Plateau des Phosphates”.

The area around 14,Adarouch and 15,Sidi-Omar sites consist of mainly Devonian and Carboniferous. Dam sites are of Turbiditic Greywacke or the alternation of Conglomerate and Mudstone where is partly schistose along some fault lines.

The site of 4,Ain-Kwachiya, 5’,N’Fifikh (Upstream), and 18,Boukarkour are also of Devonian and Carboniferous, however lithology is the alternation of Quartzite or Quartzitic Sandstone and Schist. 5,N’Fifikh (Downstream) dam site consists of Silurian Quartzitic rocks and iron ore bearing Sandstone forming very narrow gorge. However around saddle dam site and from reservoir area to upstream dam site, Permo-Triassic reddish saline argillaceous rocks interbedded with thick doleritic Basalt distribute generally. They are covered by Mio-Pliocene to Quaternary.

Topography in the area is characterized by large scale of long hills and highlands with relatively rich vegetation.

7,Amezmiz, 8,Boulaouane, and 9,Taskourt dam sites of Zone III and 23,Igui-N’Ouaqqa, 24,Amont-Abdelmoumen, and 25,Sidi-Abdella dam site of Zone IV belong to Haut Atlas Occidental Province. Haut Atlas Occidental Province is mainly composed of Precambrian basements and Paleozoic formations folded in the time of Hercynian orogeny and intruded by granitic dykes.

Among them, Amezmiz and Taskourt dam sites of northern watershed consist of a series of Schist and schistose Quartztic Sandstone of Cambro-Ordovician. From the upstream river basin of the those dam to Boulaouane dam site, Cretaceous Limestone, Marl, Mudstone, and Sandstone extend along E-W direction.

24,Amont-Abdelmoumen dam site is located in the Argana Triassic gorge, which divides into Haut Atlas Occidental calcaire to the Atlantic Ocean side and Haut Atlas Occidental to the inland side. Argana Triassic gorge consists of simple structure of Sandstone, Mudstone, and Conglomerate. Triassic formation is normally interbedded with Basalt layers.

23,Igui-N'Ouaqqa and 25,Sidi-Abdella dam sites of southern watershed consist of Upper Cretaceous Limestone interbedded with Marl, and in the case of the latter, Silurian Shale interbedded with Sandstone lie on the riverbed.

These sites are located in the mountainous area and accessibility is poor except Boulaouane site.

3,Ait-Baddou and 22,N'Ouantz dam sites of Zone III and the dam sites in Zone V belong to geologically Haute Atlas calcaire Province (Middle to Eastern Haut Atlas Province).

The former two sites are located around the border on Moyen Atlas in Northwestern watershed. While, four dam sites of Zone V are located in Southern watershed. Though lithology in this area is composed of Jurassic to Cretaceous Limestone, Marl, Mudstone, and Sandstone partly intruded by or interbedded with Gabbro to Basalt, Limestone occupies the majority portion of the area.

The basement of four dam sites in Southern watershed and Ait-Baddou dam site consist dominantly of Limestone, while N'Ouantz dam site is of Mudstone interbedded with Sandstone.

Any site in this area is located inside or the entrance of steep mountainous area.

16,Tiouine dam site of Zone IV belongs to Anti Atlas Province.

The basement is Precambrian formations overlain by continental deposits of Mio-Pliocene. Dam site consists of very hard Rhyolite interbedded with iron-manganese ore layers, while relatively loose Sandstone and Conglomerate of Mio-Pliocene cover the reservoir area.

Land depression itself of river basin around Tiouine is the tectonic basin formed by large fault group orienting N-E. Volcanic rocks such as pyroclastic flows, lavas, and ignimbrites generally fill the depression. Those rocks lie in central portion are generally coarse grained.

The details about respective dams and their surroundings are described in Tables I2.1 (1/26 ~ 26/26) and the geological sections are shown in Figures I2.1.1 ~ I2.1.25.

I3 Geology along Respective Dam Axes and the Point at Issue

I3.1 Neckor

The foundation consists of Psammitic Schist interbedded with Quartzite. Some faults are inferred at the foot of both abutments of the main dam and right abutment of sub dam. Though the imperviousness of bedrock is relatively good condition, alluvial deposits are very thick (max. 32m) so that to found directly on the bedrock may be difficult. Then the dam body shall de founded on alluvial deposits of which the bearing capacity and permeability shall be necessary to be studied carefully. Sedimentation in the river course is very much.

I3.2 Tizimellal

The foundation consists of the alternation of very hard Quartzite and siliceous Schist, which has enough bearing capacity. The upper portion of both abutments is relatively pervious showing Lugeon unit up to 15 until the depth 20 to 30 meters, however it seems to be improved easily by normal cement-milk grouting. In the mid-portion of left abutment, Sandy & Blocky Portion exists and may be pervious portion. The thickness of weathered zone is 10 to 15m in the right abutment and 15 to 20m in the left abutment of which the Lugeon unit is between 15 and 50.

I3.3 Ait-Baddou

The foundation consists of Limestone, Marl and Conglomerate in the right bank, and the alternation of Limestone and marly Limestone in the left bank. The mid-portion of right abutment is covered by Colluviums and Travertine of few meters thick. Strata in the area may be relatively permeable due that in the case of right bank side, they are porous, and in the case of left abutment, the bedding planes of the alternation are slightly suffered karst erosion and open. Their permeability shall be checked carefully and the appropriate foundation treatment shall be designed.

I3.4 Ain-Kwachiya

The foundation consists of Schist interbedded with Quartzite of which beddings dip high angle or almost vertical. Their Lugeon unit become lower than 5 from few meters depth at any points, that is good imperviousness. Though the Quartzite portion may be a little higher permeability, it seems to be improved easily by normal cement-milk grouting.

I3.5 N'Fifikh

I3.5.1 Downstream

The foundation consists of hard Quartzite and Quartzitic Schist. Faults exist at the foot of right abutment and in the middle of left abutment. Lugeon unit shows relatively low except the portion along faults, however the groundwater level of left abutment is low so that their perviousness shall be carefully checked. Along faults, especially of right abutment accompanied by sheared zone may be highly permeable portion. Foundation treatment shall be indispensable.

I3.5.2 Upstream

The foundation consists of Schist (the alternation of Pelitic Schist, Psammitic Schist, and Quartzitic Schist) interbedded with one vertical Quartzite bar of around 10m thick. Left bank nearby dam axis is disturbed so that faults and folding are inferred around there. From the viewpoint of shearing resistance, bedrock has a problem as the foundation concrete facilities. Fill type of dam may be appropriate at this site.

I3.6 Tazarane

The foundation consists of Mica Schist. Thickness of highly weathered zone, of which seismic velocity is between 0.9 to 1.2km/sec, is about 10m from the surface. The zone of seismic velocity around 3.0km/sec underlies with 30 to 40m thick, then the sound bedrock of 4.0km/sec velocity continues. However Lugeon unit shows over 20 up to the 3.0km/sec velocity zone, then imperviousness of the foundation is the problem.

I3.7 Amezmiz

The foundation consists of Schist intruded by Microgranite dykes. Schist is relatively fresh from surface and Microgranite is very hard. However on the upper portion of right abutment, soft Mudstone overlies. Lugeon unit along the intruded line of Microgranite dyke tends to be a little higher value. The surface weathered zone where Lugeon Unit is over 50 is few meters thick in the left bank side, and around 15 meters in the right bank side. The thickness of river deposits is around maximum 10m.

I3.8 Boulaouane

The foundation on the dam axis consists of mainly Limestone Bar that is interbedded by some strata of Marl towards both upstream and downstream. Limestone itself probably has a problem from the viewpoint of foundation imperviousness due that their joints are slightly open and suffered karst erosion.

However if grouting along dam axis shall be carried out sufficiently, then due to the distribution of relatively impervious Marl strata in both upstream and downstream, the leakage from reservoir through both bank sides may be few.

Terrace deposits and Travertine extend both banks with terraces of relative height 10 to 30m from riverbed.

I3.9 Taskourt

The foundation consists of the alternation of Psammitic and Pelitic Schist partly interbedded with the lens of Quartzite. However in the upper portion of left abutment, hard and slightly folded Quartzitic Sandstone overlies discordantly on the strata of Schist, and in-between contact plane (joint plane) dips towards riverside. Sedimentation on the riverbed may be large volume, and its thickness may be inferred to reach 20m.

I3.10 Timkit

The foundation consists of mainly Limestone and Dolomite. Many karst erosion develops generally resulting Lugeon Unit over 20 at everywhere sometimes over 100. Leakage may happen commonly. Siltstone layer lies under Limestone and outcrops around the river outlets in the downstream. Because that those are dipping towards the upstream and being probably impervious, there is some possibility to shield the leakage in case grouting will be able to be carried out effectively.

Sedimentation on riverbed is relatively large, and the thickness becomes maximum 15m.

I3.11 Tadighost

The foundation consists of the alternation of Limestone and marly Sandstone of which bedding is almost horizontal. In case of Limestone, their joints develop well and are frequently open then leakiness. However if grouting shall be carried out effectively utilizing impervious marly strata, there is some possibility to stop leakage.

Sedimentation on riverbed is very large, and the thickness is inferred to reach more than 20m.

I3.12 Tiouzaguine

The foundation consists of Limestone, Mudstone and Basalt from upper to lower. Travertine lies as the uppermost layer on right bank side. The depth to the impervious strata of Lugeon Unit lower than 5 is 20 to 25m in the left bank side, while reaches around 40m in the right bank side.

River deposits are relatively thick showing a little more than 10m.

I3.13 Kheng-Grou

The foundation consists of some type of Limestone. They are commonly composed of thick strata and massive, of which bedding is almost horizontal. Partly karst erosion develops along bedding planes.

River deposits are relatively thick and reaching maximum 15m.

I3.14 Adarouch

The foundation consists of the alternation of Schist and Sandstone interbedded with Conglomerate. The thickness of surface weathered zone is around 7 to 8m, and Lugeon Unit is commonly over 20 up to the depth around 10m from ground surface. Some faults cross on left abutment. Along discontinuous lines such as faults mentioned before and bedding etc., weathering and rock deterioration may develop, and then Lugeon unit along those lines may be higher.

I3.15 Sidi-Omar

The foundation consists of the alternation of Mudstone and Sandstone interbedded with Conglomerate. Left abutment is disturbed and schistose, and then faults are inferred in the left bank side.

I3.16 Tiouine

The foundation consists of Rhyolite interbedded with black iron-manganese ore strata. Though some faults are inferred to be crossing on both abutments, bedrock is commonly very hard and has enough shearing resistance. Even pervious, it may be improved easily by grouting. However on the reservoir bed, loose and permeable Sandstone and Conglomerate extends widely even on left bank, then careful study for leakage from reservoir is necessary.

I3.17 Azghar

The foundation consists of the alternation of black Limestone and calcareous Mudstone. Though their two facies are distinguished easily on the weathered rock-face, fresh portions are contacted very well and massive and difficult to distinguish each other. Both their shearing resistance and imperviousness may seem to be excellent conditions. The thickness of surface weathered zone is 2 to 3m. Few meters thick Alluvial and/or Colluvial deposits accumulate on the bottom of wide valley.

I3.18 Boukarkour

The foundation consists of mainly Quartzite containing a lot of iron ore mineral partly accumulated as hematite layers. They are interbedded with some thin Schist. Quartzite is generally very hard and has enough shearing resistance. Foundation imperviousness is also excellent where Lugeon Unit is normally lower than 5 except around ground surface (depth less than few meters).

I3.19 Aouli

The foundation consists of Schist interbedded with Limestone, Sandstone and Mudstone. Generally few meters thick topsoil or alluvial deposits cover the bedrock; especially the saddle behind right abutment is covered by around 10m thick overburden. The depth to sound bedrock where seismic velocity is between 3.1 and 3.6km/sec is 10 to 15m on riverbed and right abutment, and around 15m on left abutment. The depth to relatively impervious zone (Lu<10) is 10 to 15m on both abutments and very deep around 40m at the foot of both abutments on riverbed.

I3.20 Sidi-Abbou

The foundation consists of Limestone. Their bedding structure is not clear due to ambiguous bedding plane, but be probably almost vertical. They are relatively crystalline and hard, and then have enough shearing resistance. However, the upper portion of both abutments is weathered gradually bearing muddy material, and some portion become marl. Joints are relatively few, but commonly open with one to few centimeters. At the downstream nearby dam axis, large karst erosion develops along the line of probable tectonic zone.

I3.21 Sidi-el-Mokhi

The foundation consists of Pelitic Schist interbedded with black Limestone. Limestone and fresh Schist is relatively hard, but weathered Schist is commonly weak. Bedrock may be weathered and deteriorated along faults and joints so that the cracky portion may have the shortage of shearing resistance. Careful study may be necessary for the foundation as concrete facilities. At the upstream nearby dam axis, tectonic zone is inferred orienting from right bank upstream to left bank downstream. The slope of left bank side on that probable tectonic zone collapses.

I3.22 N'Ouantz

The foundation consists of Mudstone interbedded with Sandstone. Due to Mudstone dominant foundation, its shearing resistance may sometimes be shortage for concrete facilities. Careful study shall be necessary.

Probably fill type of dam is much suitable more than concrete type. Bedrock may seem to be impervious. Few meters of silty clay with some gravel accumulate on the riverbed. Relatively thick cobble and boulder distribute on the upper portion of right abutment probably as Terrace deposits.

I3.23 Igui-N'Ouaqqa

The foundation consists of basically Limestone, but it is underlain by layers of Sandstone, Gypsum, and Mudstone. Karst erosion develops very well resulting the most portion in the strata Lu>50. Though Limestone itself is hard and has enough shearing resistance but leakage may commonly happen even grouted.

I3.24 Amont-Abdelmoumen

The foundation consists of Sandstone or the alternation of Sandstone and Mudstone partly interbedded with Conglomerate. Some of Mudstone layers have slumping structures. Generally, their structure is simple dipping monoclinic around 30° towards left bank downstream, however partly some faults dislocating few meters to tens and few meters can be observed. Sandstone and Conglomerate are medium hard and have enough bearing capacity, but in case Mudstone it is relatively soft. Careful study shall be necessary as the foundation of concrete facilities. Some portion of Conglomerate is cracky and joints open. Imperviousness at the portion Conglomerate extends has the problem for leakage.

I3.25 Sidi-Abdella

The foundation consists of Shale interbedded with Sandstone on the bottom of valley and Quartzitic Sandstone and Limestone on both abutments. Basalt dyke runs obliquely crossing high angle with water course orienting from right bank upstream to left bank downstream at the upstream nearby dam axis. Shall is generally very brittle with low shearing resistance so that it may not be suitable for the foundation for concrete type of dam. Shale is usually impervious where Lugeon Unit is generally lower than 5, however faults are inferred on left abutment where may be pervious. In the Limestone layers of both abutments, karst erosion develops very much and leakage may happen commonly. Relatively thick (around 10m) Terrace deposits and Talus deposits extend along the foot of right bank side.

I4 Earthquakes

In the Figure I4.1.1, it is shown the seismic events of magnitude over 4 around Morocco during about 100 years of 1900's. However during 1900 to 1910, data of relatively large seismic events have not been obtained due to insufficient survey system.

According to those data, around the area of Mediterranean Sea and from Rif Mountains through Moyen Atlas to Middle～Western Haut Atlas, earthquakes happen frequently.

From the result of the earthquake distribution of magnitude more than 5, high-risk area is around Neckor, the neighborhood of Tazarane, and along South Atlas Line especially around Erracidia and Agadir. Though the area around Sidi-Omar is low frequent, once happened. The location of hypocenter of magnitude more than 5 in the Atlantic Ocean area looks being on one line and the point around Sidi-Omar is located on this line. There is some possibility they are related each other. The neighborhood of Erracidia is also on this line.

I5 Construction Material

Construction material study results mentioned in the respective dam study reports are shown in Tables I2.1 and were compiled in the Tables I5.1.