Chapter 3 Investigation related to Water Resources

3.1 Method of Water Resources Investigation

The water resources investigation was conducted along the flowchart shown in Figure 3-1-1.
This chapter includes contents from "analysis of existing data" to "evaluation of water potential", and "groundwater model (prediction)" is described in Chapter 8.

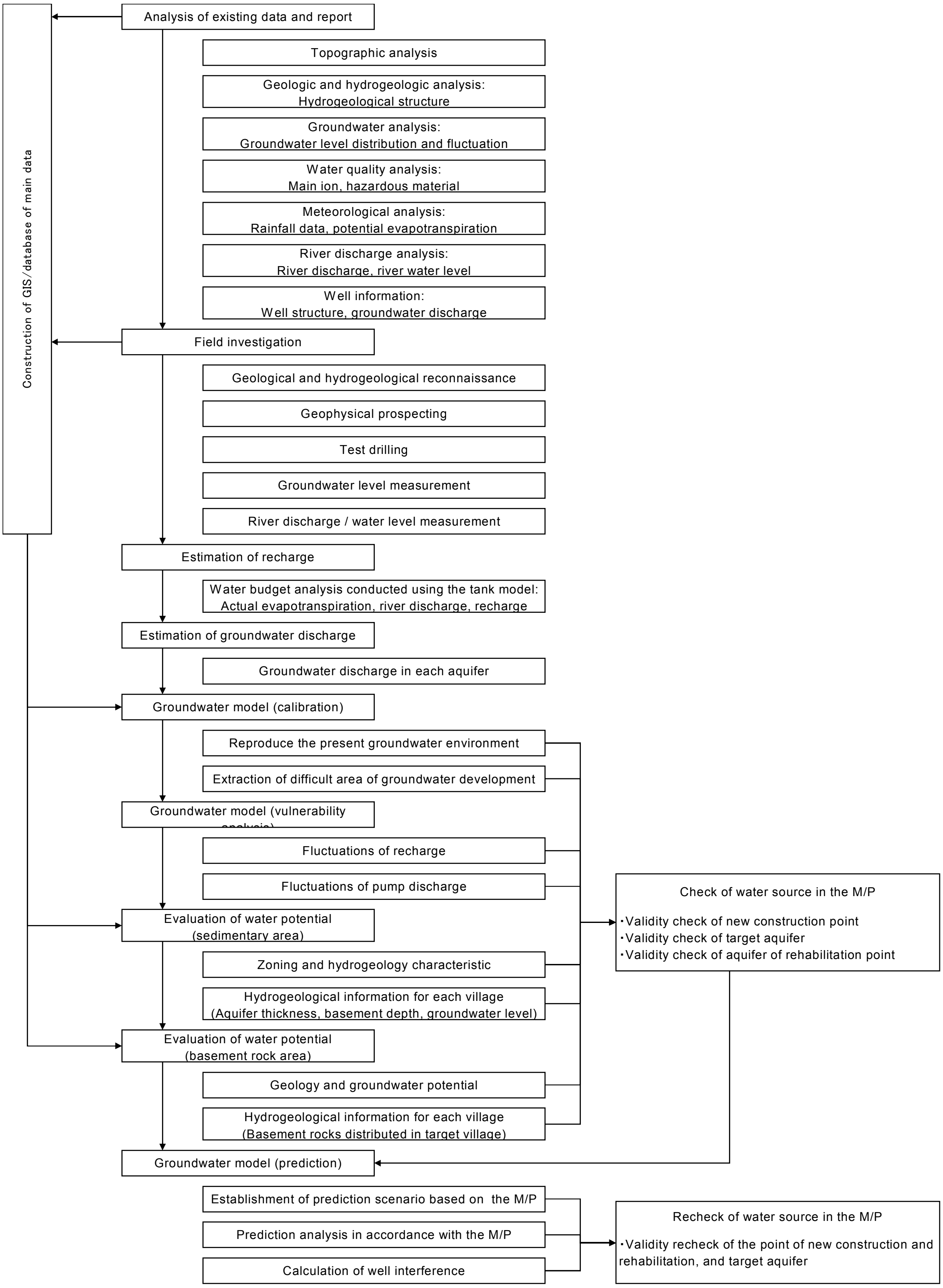


Figure 3-1-1 Flowchart of water resources investigation

3.2 Collection, Arrangement and Analysis of Existing Data and Report

3.2.1 Collected Existing Data

Main data and existing reports that were collected, arranged and analyzed in this project are as follows. These collected data were used as basic material of the water resource potential evaluation described in Section 3.4.

- Topography and surveying (including digital elevation data)
- Geological map, geological structure map, hydrogeological map and mining geological map
- Existing reports related to geology, hydrogeology and groundwater (Including well drilling and modeling)
- Geophysical survey
- GIS / Database
- Meteorology
- River discharge

3.2.2 Topographic Analysis

A shaded map and topographic profile of the survey area were made based on the digital elevation data of SRTM-90 and the regional topographic feature of the target area was clarified.
The following are some of the topographic features in this project area:

- A cliff exists in the vicinity of the Guinean border.
- Hills of basaltic rock distribution and other formations exist
- There is a gradual inclination from the southeast to northwest direction.
- In this gradual inclination, there is an area of lowland with a steep inclination on its northwest side and a gradual inclination on its southeast side.
- There is a rise on the west bank of the Senegal River and a gradual inclination towards the southwest.

3.2.3 Geological and Hydrogeological Analysis

(1) Outline of geology and hydrogeology
The aquifers distributed in the project area are divided into (i) Mastrichtian aquifer (hereafter, Ma aquifer), (ii) Paleocene aquifer (hereafter, Pa aquifer), (iii) Eocene aquifer (hereafter, Eo aquifer), (iv) Continental terminal / Oligo-Miocene aquifer (hereafter, Co aquifer) and (v) Quaternary aquifer (hereafter, Q aquifer) in ascending order. Outlines of these aquifers and basement rocks are described as follows.

1) Basement rocks
The main rocks distributed in the southern part of this project area are composed of basaltic rocks (basalt, dolerite (coarse basalt), spilite, etc.), carbonate rocks (limestone, marl, etc.), granitic rocks (granite, aplite, etc.), schist (green schist, mica schist, amphibolite, etc.), quartzite, and arenite (sandstone, siliceous schist, greywacke, etc.). Moreover, dikes that consist of pegmatite and quartz vein, etc. are intrusive in the above-mentioned rocks.

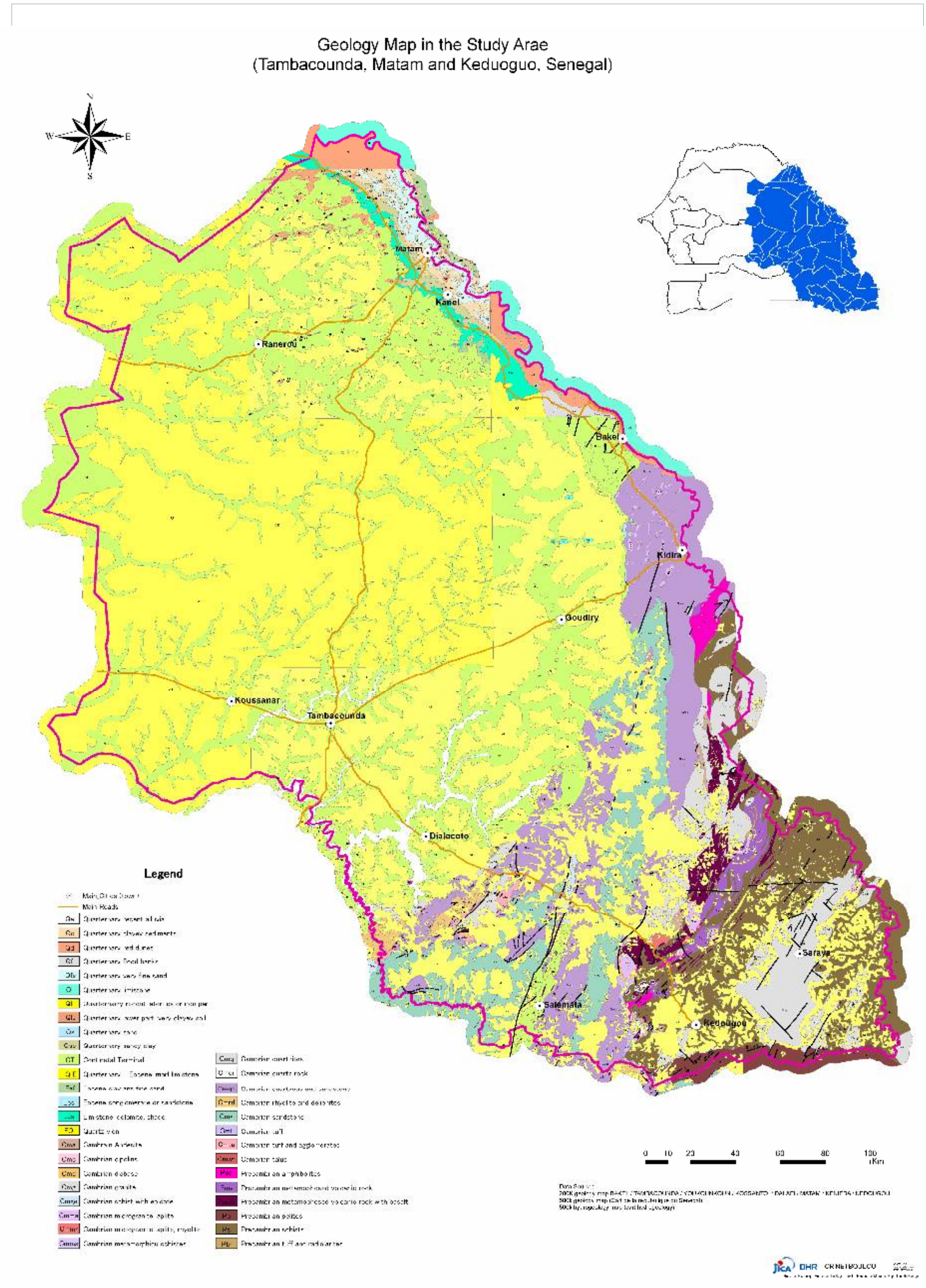


Figure 3-2-1 Geological map edited by this project

Table 3-1-1 Hydrogeological stratigraphy classification of Senegal

ERE	PERIODE GEOLOGIAUE				Regroupement Strati	Zond Nord		Système Aquifère	Zond Sud	
	Syst.	Série	Etage			Lithologie dominante	Aqui..		Lithologie dominante	Aqui..
QUATERNAIRE					Ensemble supérieur	Sables éoliens alluvions tufs volcaniques	Aauifère	"Complexe Terminal"	Sables marins et éoliens	Aauifère
TERTIAIRE	NEOGENE	PLIOCENE	"CONTINENTAL TERMINAM"			Sables coquilliers sables +/- argileux	Aquitard		Sables ou grès argileux et argiles	Aauitard
		MIOCENE				Marno calcaire	Aquitard		Sables avec bancs d'argile et calcaires	Aauifère
		OLIGOCENE				Marnes et agiles	Aquitard			
	PALEOGENE	EOCENE	moy	LUTETIEN SUP.	Ensemble intermédiaire	Calcaires marno-calcaires	Aquiclude	"Système Aquifère du Paléogène"	Calcaires karstifiés	Aauifère
				LUTETIEN INF.		Sables	Aauifère		Marno calcaires passés sable	Aauitard
			inf	YPRESIEN		Marnes et agiles	Aquiclude			
		PALEOCENE	PALEOCENE sup. à moyen			Marno-calcaires calcaires karstifiés marnes	Aauifère		Sables calcaires coauilliers ou karstifiés	Aauifère
			DANIEN			Marno calcaires	Aquitard		Marno calcaires argiles	Aauitard
SECONDAIRE	CRETQCE	CRETACES Supérieur	SENONIEN	MAASTRICHITIEN	Ensemble Crétace sup.	Sables grès, sables gréseux sables argileux	Aauifère	"Système Maastrichtien"	Sableux avec passées d'argile	Aauifère
				CAMPANIEN		Grès Sables argileux	Aauifère		Sables argileux	Aauifère
				SENONIEN INF		Sables argileux et argiles sableuses	Aquitard		Argile sableuse	Aauitard
			TURONIEN			Argiles noires	Aquiclude		Argiles noires	Aquiclude
		CRETACES moyen	CENOMANIEN		Ensemble inférieur	Calcaires argiles sableuses	Aquiclude		Marno calcaire	Aquiclude
			ALBIEN			Calcaire, marno calcaire sables argileux			Marno-calcaires, argiles sableuses	
			APTIEN			Calcaire, marno calcaire argiles sableuses			Marno-calcaires, argiles sableuses	
		CRETACES inférieur	NEOCOMIEN			Calcaire dolomitique				
	JURASSIQUE					Calcaires, calcaires dolomitiques	Aquiclude		Calcaires et bancs de dolomie	Aquiclude
	TRIAS					Counche salifère	Aquiclude		Counche salifère	Aquiclude
PRIMAIRE					-Socle-	Argiles siliceuses grès quarizites conglomérats	Aquiclude		Argiles siliceuses grès quarizites conglomérats	Aquiclude
SOCLE CRISTALLIN						Granites, diorites, roches métamorphiques		Aquifère dans les zones superficielles fracturées et arénisées		

(Source: COWI (September 2001), the color division of an aquifer, aquitard and aquiclude was made by this project.)

2) Mastrichtian aquifer (Ma aquifer)
Upper Cretaceous Ma aquifer is widely distributed in this project area and the distribution of this aquifer's bottom depth is deep westward. This aquifer is marine sediment and consists of sandstone, muddy-sand and sand in ascending order. It is thought that black clay is distributed in the lowest part. Moreover the black clay layer is often distributed in the boundary with the Paleocene aquifer.

3) Paleocene aquifer (Pa aquifer)
The Pa aquifer is a deposit of the transgression period after the Cretaceous and is mainly composed of carbonate rocks. Muddy part (marl) is widely distributed and the permeability of the muddy layer is

low.

4) Eocene aquifer (Eo aquifer)
It is thought that the Eo aquifer is a deposit of the transgression period following the Pa aquifer and this aquifer is exposed in the northeast part of this project area. Marlaceous and pelitic rocks/layers are predominant in this aquifer with occasional intercalations of limestone and calcareous sand. This limestone and calcareous sand is the main aquifer in this formation.

5) Continental terminal / Oligo-Miocene aquifer (Co aquifer)
Though this aquifer is named the Continental terminal aquifer, it is sometimes also called the Oligo-Miocene aquifer. This aquifer consists mainly of muddy sand and fine sand with calcareous parts. This aquifer is thick in the southwest part of Tambacounda Region. This aquifer has developed as the main aquifer there, because the Ma aquifer is distributed deeply.

6) Quaternary aquifer (Q aquifer)
Quaternary aquifer is composed of marine carbonate layers with shells, lacustrine deposits, aeolian deposits, etc. Groundwater development in the alluvial layer distributed along the Senegal River is one problem in this project area.

(2) Hydrogeological structure
The drilling records of individual wells were arranged as geological columns. Moreover, the geological profiles were compiled to prepare the cross section below (Figure 3-2-2) and were used as basic data for hydrogeological structure analysis.

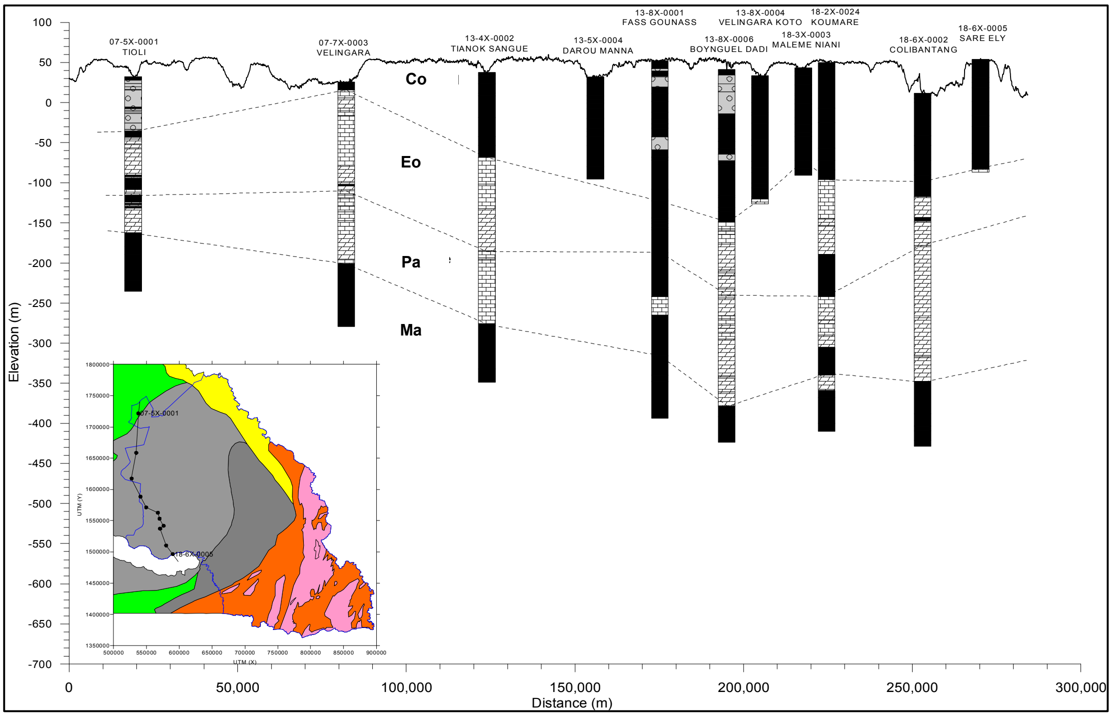


Figure 3-2-2 Examples of geological profiles

Moreover, the distribution map of thicknesses of aquifers (Figure 3-2-3) and the distribution map of the basal surface depths of aquifers (Figure 3-2-4) were made using the geological columns that were arranged as above.

The distribution depths of basement rocks become rapidly deeper along the boundary with the sedimentary area and become deeper towards the west. Moreover, distribution has a gentle valley shape from Tambacoiunda to the west side. The distribution depth of the Ma aquifer becomes deep from the east of Tambacounda to the surroundings of the southwestern part of the region. The east boundary of this area runs in a north-south direction and the distribution depth changes rapidly. Because the area from the eastern part of Matam region to the surroundings of Goudiry is located on the east side of this boundary, and the thickness of Co aquifer is thin, only the Ma aquifer is the target for groundwater development.

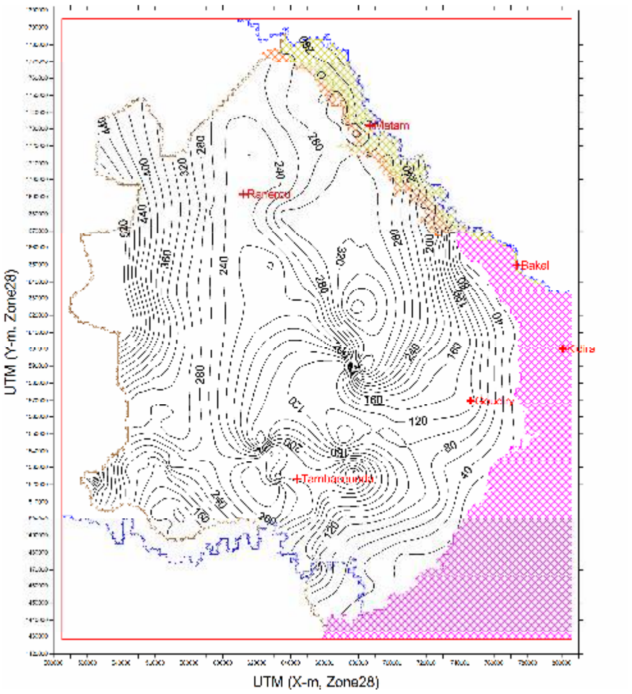


Figure 3-2-3 Example of distribution of aquifer thicknesses (unit: m)
(Ma aquifer)

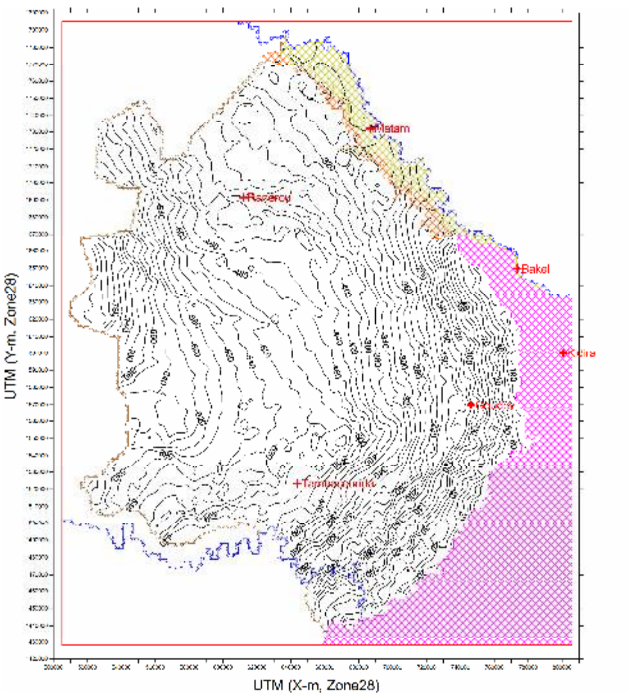


Figure 3-2-4 Example of distribution of basal surface depths of aquifers (unit: m)
(Ma aquifer)

3.2.4 Groundwater Level and Groundwater Flow

(1) Groundwater level fluctuation (DGPRE monitoring data collection and arrangement)
The specifications of DGPRE monitoring wells are arranged in Table 3-2-2 and situation of groundwater level fluctuation of each monitoring well is shown in Figure 3-2-5. These data were used as the groundwater model's verification data.

Table 3-5-1 Specifications of DGPRE monitoring wells

No_IRH	Village	Longitude (°)	Latitude (°)	UTM (X)	UTM (Y)	Aquifer	Well type*	Elevation of control point （m） **
20-1X-0001	BANTANANI	-12,9750	13,7222	718 982	1 517 922	Ma	Borehole	56,88
13-2X-0002	BELEL TOUFFLE	-14,5347	14,8856	550 050	1 645 725	Ma	Borehole	23,19
15-7X-0001	BOYNGUEL BAMBA	-12,9400	14,0942	722 413	1 559 118	Ma	Monitoring well	52,07
09-7X-0016	DIALLOUBE DIAMOUNGUEL	-12,9250	15,1111	723 005	1 671 667	Ma	Borehole	54,42
18-6X-0007	FADIACOUNDA	-14,1611	13,6269	590 741	1 506 620	Co	Borehole	10,30
08-6X-0011	KANEL F4	-13,1811	15,4883	695 123	1 713 163	Ma	Monitoring well	(25,62)
14-1X-0002	KARE KABI	-13,8861	14,7514	619 896	1 631 127	Ma	Borehole	53,46
13-1X-0005	KHOUMOUK	-14,8075	14,9917	520 696	1 657 417	Ma	Compound well	(49,48)
18-2X-0009	KOUNDIAO SOUARE	-14,5167	13,8000	552 237	1 525 660	Ma	Compound well	31,79
19-2X-0002	MAYEL DIBI	-13,6431	13,8861	646 617	1 535 546	Co	Borehole	21,37
08-8X-0001	NAMARY	-13,6456	15,0822	645 564	1 667 865	Ma	Compound well	39,62
18-5X-0004	PAKEBA	-14,3625	13,5556	568 976	1 498 669	Co	Borehole	15,74
08-7X-0001	RANEROU	-13,9569	15,3042	611 986	1 692 241	Ma	Borehole	(40,74)
14-8X-0001	SINTHIOU BOCAR ALI	-13,5681	14,2319	654 490	1 573 848	Ma	Borehole	42,01
15-7X-0002	FETE NIEBE	-12,6800	14,2200	750 359	1 573 303	-	-	(71,59)
19-4X-0006	SOUROUYEL SALIF	-13,8600	13,5900	623 332	1 502 671	Co	Monitoring well	(32,03)
14-7X-0002	TINKOLY MANDINGUE	-13,9500	14,0400	613 376	1 552 402	Co	-	(26,91)

*: Compound well, in well type column, means upper part is hand dug well and lower part is borehole.
**: Values in brackets, in the control point elevation column, are the altitudes estimated from SRTM-3 data.

(2) Distribution of groundwater level
There is no record of simultaneous groundwater level measurements in this project area. Moreover, it is difficult to conduct new simultaneous measurements, because vertical axis pumps are installed in many of the wells under operation.

For this purpose, before the simulation analysis (verification work), a long-term transient calculation was conducted and the distribution of groundwater levels was identified (Figure 3-2-6). This result was used as initial head values for groundwater flow simulation.

(3) Groundwater flow
At present, the basic philosophy to explain groundwater resources of Senegal results from the investigation that DGPRE (executing consultant: COWI) conducted from 1994 to 2000. This investigation on nationwide groundwater potential focused on the Ma aquifer and was reported in 2001. As one of the results, the flow direction of Ma aquifer's groundwater was clarified and the possibility of recharge from a river to a groundwater was suggested (Figure 3-2-7).

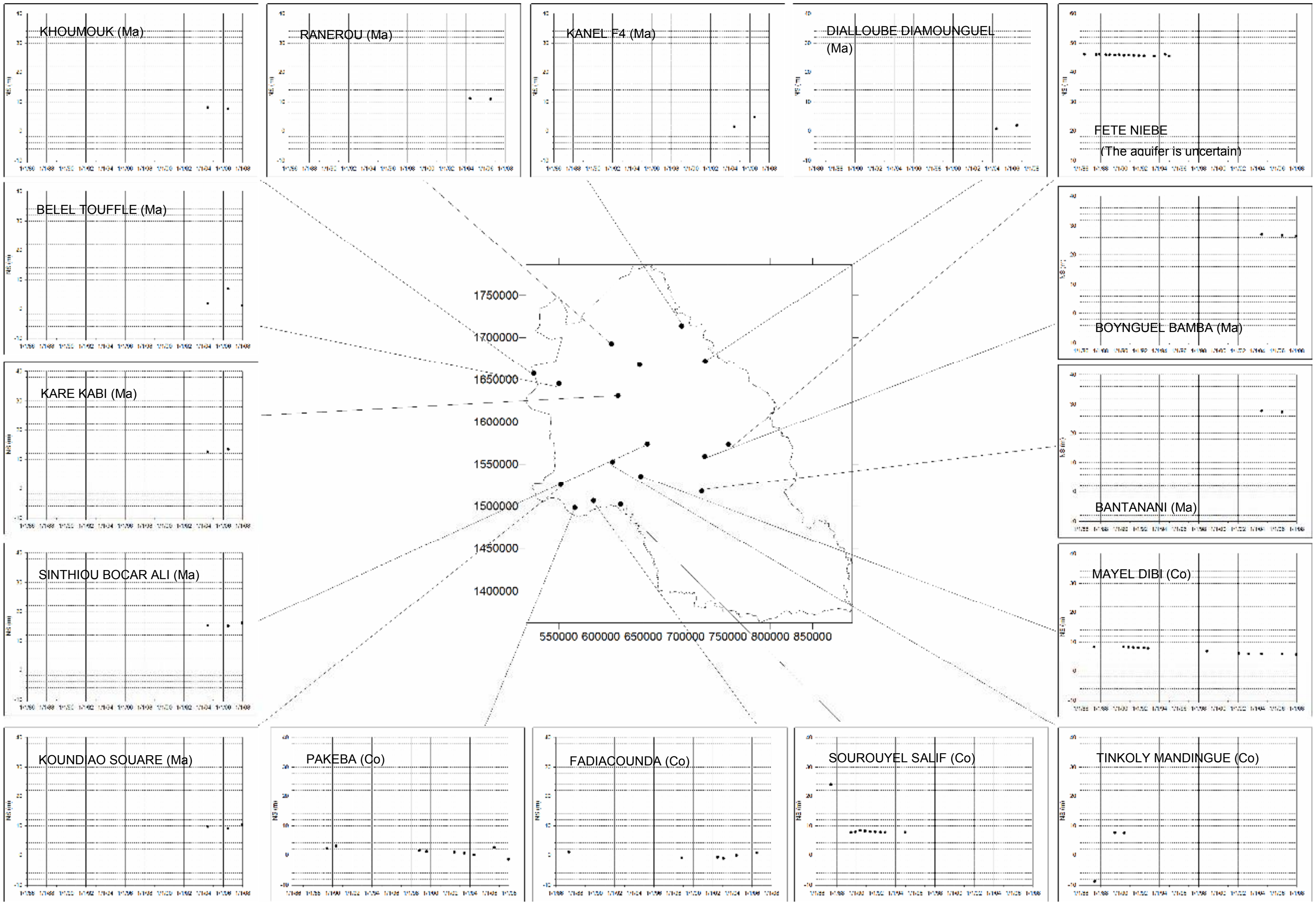


Figure3-2-5 Groundwater level fluctuations of DGPRE monitoring wells

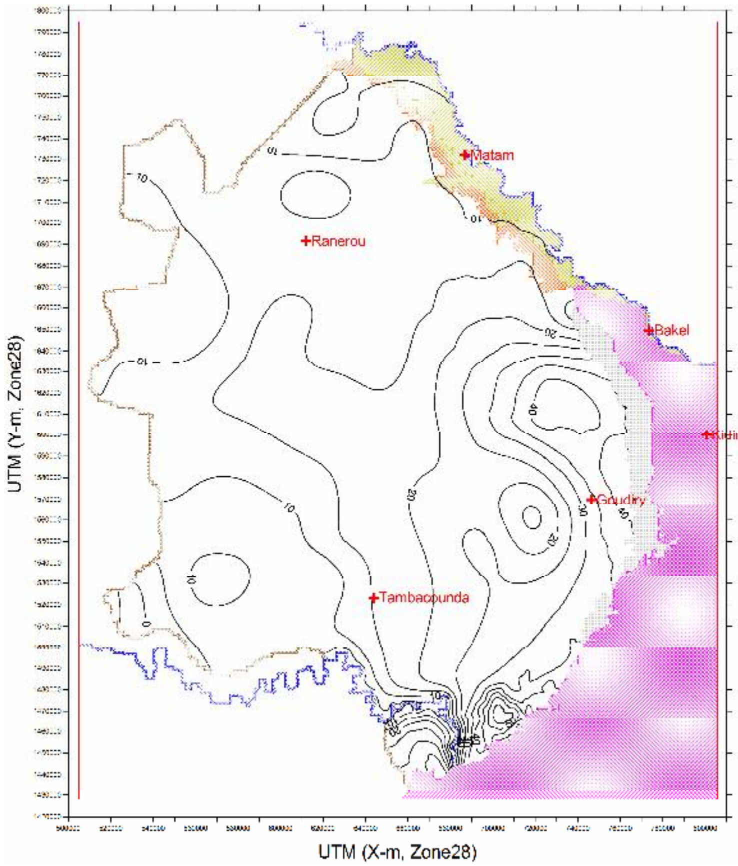


Figure 3-2-6 Example of distribution of groundwater levels (unit: elevation-m)
(Calculated initial head of Ma aquifer)

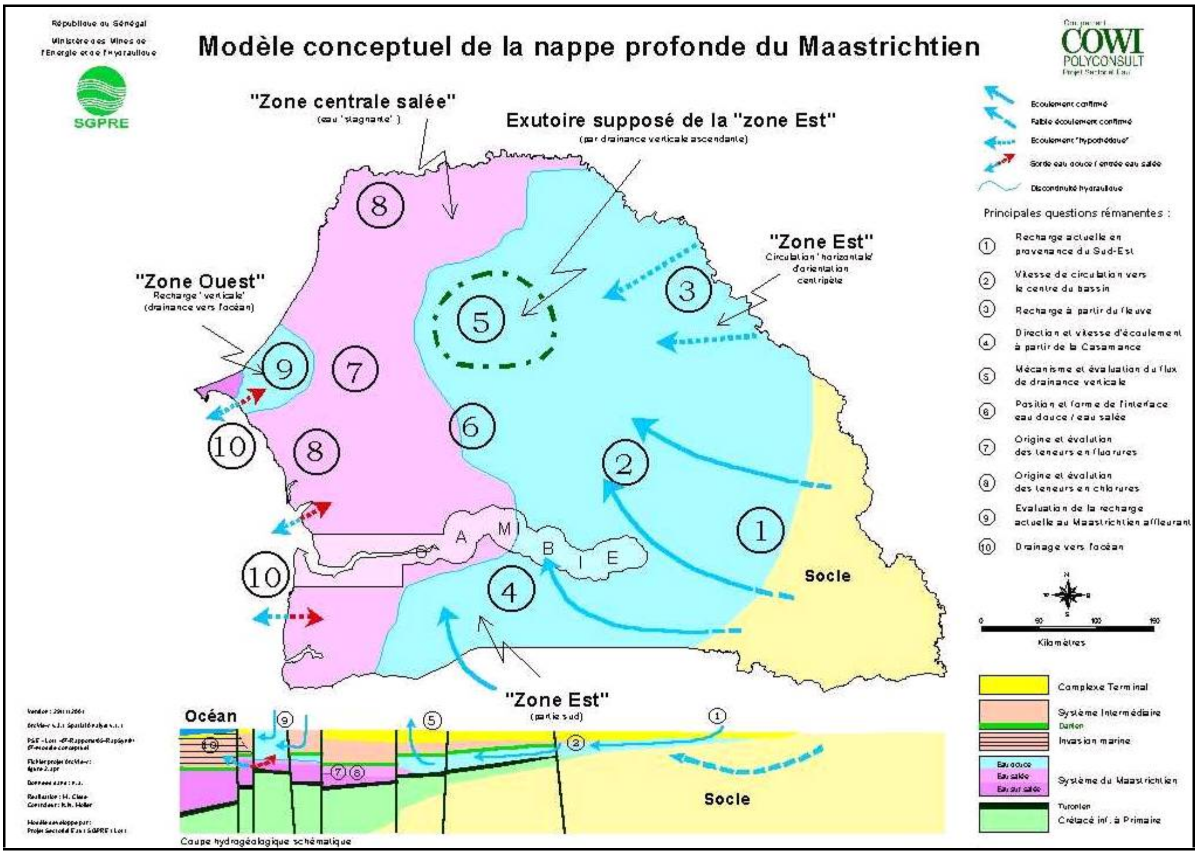


Figure 3-2-7Flow directions of Ma aquifer's groundwater

3.2.5 Water quality

(1) Main ion
Trilinear diagrams with main ions as an element system were made by using the results of water quality analyses by DGPRE.
The characters of groundwater qualities in this project area are as follows.

- Co aquifer: Many samples are from the zone classified as $Ca(HCO_3)_2$ type. This type of water often belongs to river water and shallow groundwater.
- Ma aquifer: Many samples are from the zones classified as $CaSO_4$ (or $CaCl_2$) and $Ca(HCO_3)_2$ types. The former type is mostly found in hot spring, while the latter type often belongs to river water and shallow groundwater as above.
- Basement rocks: Many samples are from the zones classified into $Ca(HCO_3)_2$ type and $NaHCO_3$ type. The former type water often belongs to river water and shallow groundwater as above and the latter type is found in deep groundwater.

3.2.6 Meteorological data analysis

(1) Rainfall data
Basic data for tank model analysis that is the calculation method for water balance analysis and estimation of groundwater recharge described in Section 3.4 are arranged using daily rainfall data of meteorological stations shown in Table 3-2-3.

Table 3-2-3 Parameters of meteorological stations used for Thiessen polygon

Station name	Country	Longitude (°)	Latitude (°)	UTM (X)	UTM (Y)	Elevation (m)
Matam	Senegal	15,650	-13,250	687 583	1 730 994	17
Semme	Senegal	15,200	-12,950	720 225	1 681 480	40
Ranérou	Senegal	15,300	-13,966	611 011	1 691 772	33
Bakel	Senegal	14,900	-12,400	779 733	1 648 898	25
Kidira	Senegal	14,300	-12,100	812 881	1 582 862	35
Goudiri	Senegal	14,183	-12,716	746 512	1 569 203	59
Tambacunda	Senegal	13,767	-13,683	642 377	1 522 347	50
Kédougou	Senegal	12,567	-12,217	802 415	1 390 852	167
Linguere	Senegal	15,383	-15,177	487 444	1 700 692	21
Dialakoto	Senegal	13,317	-13,300	684 138	1 472 821	50
Kenieba	Mali	12,850	-11,233	909 010	1 423 541	132

The regional distribution of the rainfall was divided by the Thiessen polygon shown in Figure 3-2-8.

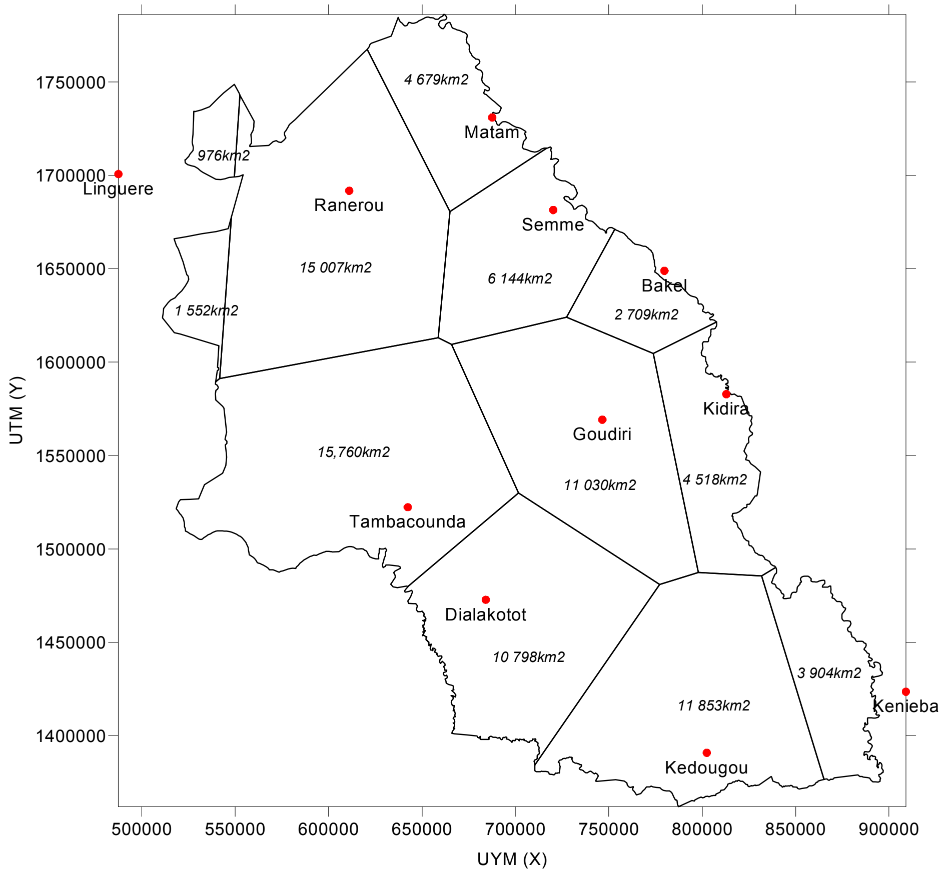


Figure 3-2-8 Thiessen polygon

(2) Estimation of evapotranspiration

In this project, the potential evapotranspiration was estimated by the Thornthwaite method. Estimations of potential evapotranspiration were conducted based on data of the above-mentioned meteorological stations used for Thiessen polygon (Five stations (Semme, Kidira, Linguere, Dialakoto, Kenieba) where temperatures are not measured are excluded). The example of the calculation results of the Matam station is shown in Table 3-2-4.

Table 3-2-4 Example of estimations of potential evapotranspiration (Matam station, unit: cm/month)

	Jan	Feb	Mar	Apr	May	Jun	Jyl	Aug	Sep	Oct	Nov	Dec
1988	5,84	13,08	17,58	18,62	20,50	19,63	19,39	17,16	16,21	17,48	14,76	7,65
1989	7,32	13,55	16,70	18,43	20,46	19,33	19,12	17,51	17,14	17,24	15,69	13,94
1990	6,04	14,14	18,06	18,77	20,50	19,75	19,39	18,14	17,14	17,90	15,10	9,20
1991	9,33	12,69	16,37	18,43	20,30	19,75	19,39	18,14	17,14	17,24	15,10	10,60
1992	8,83	13-55	16,01	18,23	20,18	19,75	19,39	18,14	17,66	18,08	14,41	13,10
1993	8,15	13-55	17,58	18,91	20,50	19,75	19,63	18,14	16,53	17,71	15,10	8,72
1994	4,87	13,08	17,30	17,18	20,39	19,63	19,12	16,78	16,53	17,24	15,40	9,65
1995	5,63	13,08	17,02	18,43	20,39	19,90	19,85	17,51	16,85	17,48	15,40	8,49
1996	13,94	14,46	17,02	18,43	20,50	19,75	19,39	17,51	17,41	17,71	15,10	8,83
1997	13,53	14,46	15,63	18,00	20,30	19,33	19,12	18,69	16,53	17,48	15,40	7,99
1998	7,70	14,75	17,30	19,10	20,46	19,90	19,39	17,51	16,53	17,48	14,76	9,04
1999	6,45	8,12	17,02	18,62	20,39	19,63	18,16	17,16	16,21	16,97	14,76	9,39
2000	10,64	12,69	17,83	19,02	20,39	19,14	18,16	16,38	16,53	16,05	14,04	9,23
2001	7,70	12,69	17,30	18,23	20,30	19,49	18,50	18,14	16,53	17,24	14,76	13,94
2002	7,41	13,08	16,70	17,75	20,39	19,49	19,39	18,14	17,14	17,48	14,76	13,10
2003	7,26	13,55	17,58	18,77	20,46	19,49	19,39	17,16	15,47	17,24	15,40	8,84
2004	7,36	13,55	16,70	18,77	20,39	19,63	18,82	17,51	16,53	17,48	15,40	13,10
2005	7,36	12,29	17,83	18,91	20,46	19,49	18,50	17,82	16,53	17,24	15,10	14,34
2006	6,82	12,69	17,30	18,91	20,30	19,75	19,85	17,51	16,85	18,08	15,10	7,65
2007	9,39	13,55	17,30	18,62	20,46	19,75	19,39	17,16	16,53	17,48	14,76	13,10

3.2.7 Investigation of River Discharge

Data of river discharge monitoring conducted by DGPRE were arranged and the characteristic of river flow in this project area was clarified. Moreover, the fluctuations of stream flows were used as verification data of the tank mode analysis mentioned below and the river level fluctuations of the Senegal River and the Gambia River were used as boundary conditions for the groundwater model.

3.3 Results of Field Investigation

3.3.1 Result of Field Reconnaissance for Geology and Hydrogeology

This investigation aimed to confirm the topographic and geological features of the project area, and to understand those characteristics.
Because outcrops of sedimentary deposits are extremely limited, field reconnaissance for geology and hydrogeology was conducted mainly in the basement rock area, and existing water supply facilities having the following topographic and the geological characteristics were targeted.

- Lower portion of the cliff along the border with Guinea
- Lower portions of hills where basaltic rocks are distributed
- Schist distributed area
- Schist distributed region (in the vicinity of the fault boundary with quartzite)
- Quartzite distributed region (in the vicinity of the fault boundary with schist)
- In the vicinity of the fault distributed in granite
- Quartz vein distributed area
- Cambrian sandstone distributed area

Outline of the investigation results is shown in Table 3-3-1. These results were used as basic data especially when the groundwater potential of each rock type in the basement rock area was examined.

Table 3-3-1 Existing water supply facilities and hydrogeology in basement rock area

Village	Topography	Geological map (scale: 1/20)	Geological structure	Aquifer	Main parameter of well					
					Drilling depth Well depth	Screen position	Static water level	Discharge	Drawdown	Water quality
Segou	Lower portion of cliff along border with Guinea	Granite	-	Schist (Birrimien) Conglomerate (Birrimien) Fault and fracture zone	40,5m 40,5m	29,1 - 40,5m	16,1m	10m^3/h	6,6m	-
Dindéfello	Lower portion of cliff along border with Guinea	Granite	-	Granite Fault and fracture zone	58,4m 56,9m	32,3 - 56,9m	6,8m	10m^3/h	35,6m	-
Ibel	Lower portions of hills where basaltic rocks are distributed	Basaltic rocks, etc.	-	Schist Fault and fracture zone	37,6m 35,8m	11,2 - 35,8m	7,1m	30m^3/h	9,6m	-
Salemata	Surroundings are small hills.	Schist	-	Crystalline schist, Quartz vein	88,15m 70,15m	28,15 - 64,15m	6,15m	9m^3/h	19,8m	-
Ebarak	-	Boundary of schist, quartzite, and sandstone	Surrounding of fault	Schist (Paleozoq) Fault and fracture zone	49,0m 48,7m	14,6 - 48,7m	6,6m	4,3m^3/h	6,1m	Iron (5,0mg/)
Banfarato	-	Boundary of quartzite and schist	Surrounding of fault	Pelite Fault and fracture zone	45,0m 45,0m	27,9 - 45,0m	5,0m	1,4m^3/h	12,6m	-
Bandioula	-	Granite	Fault	Gabbro?	45,1m 40,25m	-	7,28m	19,5m^3/h	1m	-
Kondokhou	-	Granite	Fault	Granite	45,0m	16,4 -	11,1m	5,4m^3/h	19,5m	Iron

Village	Topography	Geological map (scale: 1/20)	Geological structure	Aquifer	Main parameter of well					
					Drilling depth Well depth	Screen position	Static water level	Discharge	Drawdown	Water quality
				Fault and fracture zone	45,0m	45,0m				(> 5,0mg/)
Daloto	-	Schist, quartzite, greywacke, conglomerate, etc.	Quartz vein	Schist (Birrimien) Fault and fracture zone	45,1m 45,0m	37,8 - 45,0m	22,6m	12m³/h	10,6m	Iron (5,0mg/)
Bellé	Between small hills	siliceous sandstone	Surrounding of fault	Quartzite (Cambrian) Fault and fracture zone	58,6m 58,6m	30,0 - 58,6m	23,1m	3,5m³/h	-	-

3.3.2 Test Drillings

The primary objective of test drillings is to confirm the potential of groundwater. Furthermore, the drilling points were selected according to the secondary objective which is construction of water sources for water supply facilities,

1) Boundary of sedimentary rock area and crystalline rock area.
2) Confirmation of thickness of alluvium on the crystalline rock.

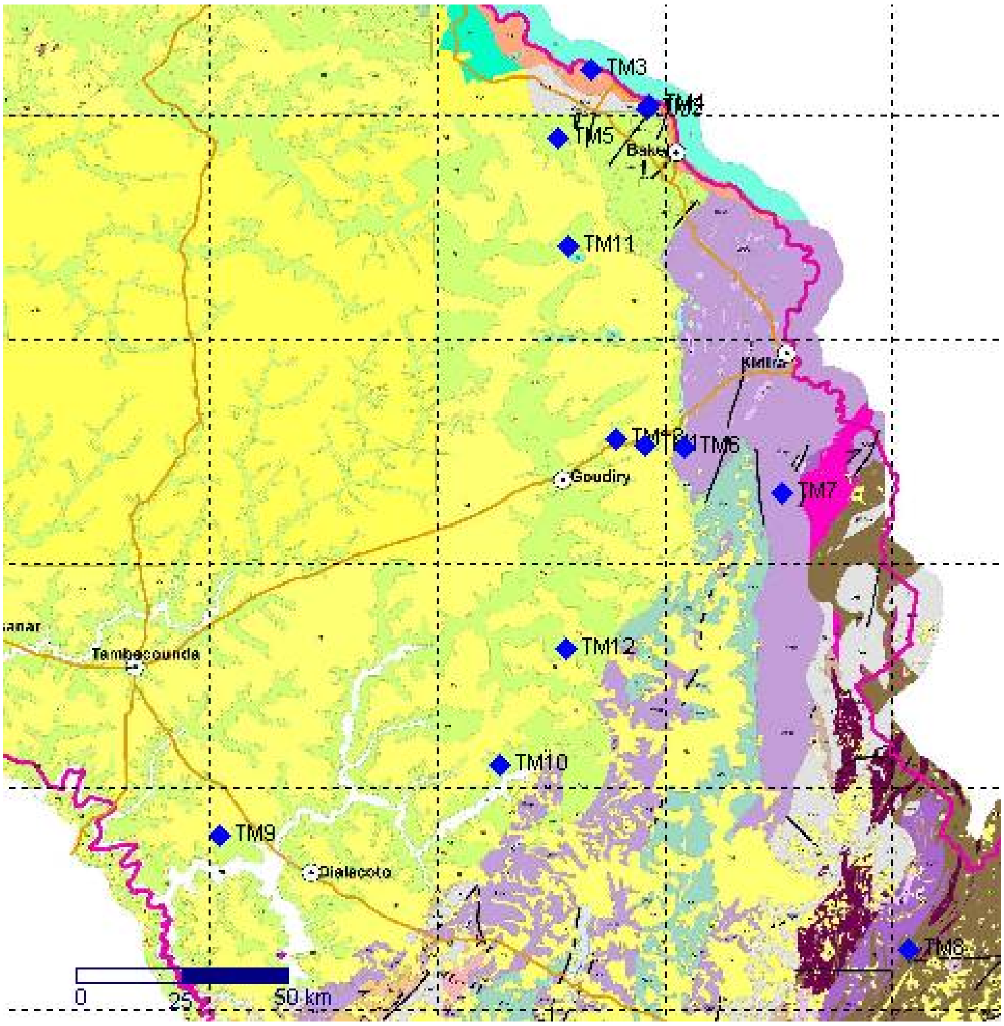


Figure 3-3-1 Test drilling points

Tableau 3-3-2 Specifications of drillings

Target aquifer	Method	Target depth	Drilling diameter	Casing Diameter
Fracture in the crystalline rock	MTF	150m	8 inches	6 inches PVC
Sedimentary rock (not consolidated)	Rotary	Depth of crystalline rock (100-200m)	14 inches	8 inches PVC
		Depth of crystalline rock 450m	Upper 14-3/4 inches Lower 8-1/2 inches	Upper 10 inches PVC Lower 4 inches SUS

(1) Summary of drillings
The results of drillings are summarized in Table 3-3-3.

Tableau 3-3-3 Results of drillings

No.	CR	Village	Aquifer	Depth (m)	Depth of rock (m)	Casing depth (m)	SWL (m)	Pump test 12H		
								Discharge (m^3/h)	DWL (m)	drawdown (m)
TM1	Goudiry	AinouMahdi	Ma	72,0	64	70,8	49,3	44,0	53,4	4,1
TM2	Commune	Diawara1	Alluviale	25,0	12	22,3	2,9	3,4	14,9	13,0
TM3	Moudery	Gande	Alluviale	26,1	25	26,0	10,4	71,1	11,9	1,4
TM4	Commune	Diawara2	Alluviale	24,0	21,5	23,6	10,6	21,5	6,4	6,5
TM5	Bokiladji	GangelMaka	Socle	121,0	26	58,9	12,9	35,8	45,2	32,2
TM6	Sinthou Fissa	YariMale	Socle	151,0	18	86,6	46,7	1,5	82,6	36,0
TM7	Shinthou Fissa	Takoutara	Socle	98,0	5	82,1	9,84	13,3	3,4	3,6
TM8	Khossanto	Khossanto	Socle	150,0	9	92,2	8,1	8,1	71,0	62,8
TM9	Missirah	Medina Diakha	Ma	250,0	248	250,0	17,5	62,7	28,3	10,8
TM10	Bani Israel	Diana	Ma	91,0	60	81,6	18,4	15,5	44,7	26,3
TM11	Aoure	Tiendiel Demba Djibi	Ma	88,0	88	87,0	43,9	55,2	49,7	5,8
TM12	Dougue	Soutouta	Ma	61,0	61	60,2	13,7	66,0	10,8	10,8
TM13	Goudiry	Dinde Daka	Ma	84	84	81	34,5	62,8	36,1	1,6

3.3.3 Groundwater level measurement conducted in this project

(1) Objective and method of this survey
The purpose of the groundwater level observation in this project is as follows. The site selection was conducted according to this viewpoint in August and November 2008.

- Completion of the measured points in the World Bank project (Etude hydrogéologique de la Bordure sédimentaire du Sénégal Oriental) and identifying the groundwater level (especially in the Ma aquifer) throughout the entire sedimentary area of this project
- Comparison of shallow groundwater levels and water levels of nearby rivers
- Continuous monitoring of groundwater levels at main measurement points

The observation method is as follows.

- Weekly measurements using a portable water level meter at 11 shallow wells
- Weekly measurements using a portable water level meter at 9 deep wells
- Continuous measurements using an automatic water level meter at 3 deep wells

The measurement points are as shown in Figure 3-3-1 and Table 3-3-2.

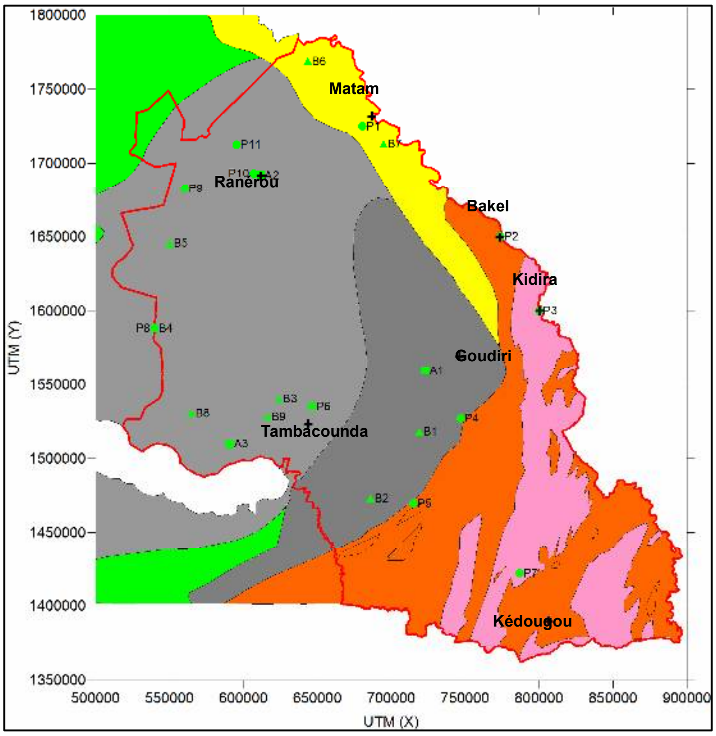


Figure 3-3-2 Location map of groundwater level measurement points in this project

Table 3-3-4 Coordinates of groundwater level measurement points in this project

No,	Village	ID_IRH	UTM (X)	UTM (Y)	Elevation (m)
Hand dug well					
P1	OURO SOGUI		680 306	1 725 123	17,950
P2	BAKEL		773 636	1 650 199	24,744
P3	KIDIRA		799 937	1 600 202	31,180
P4	SOUTOUTA		746 897	1 527 139	85,030
P5	MANSADALLA		714 886	1 469 637	30,714
P6	MàYéL DIBI		646 688	1 535 074	23,093
P7	MAKO		786 846	1 422 010	82,298
P8	DAROU MANA		539 832	1 588 413	28,141
P9	NAKAR		560 229	1 682 875	36,250
P10	BELE NDENDI		606 787	1 693 220	28,900
P11	VENDOU KATANE		595 269	1 712 572	48,410
Borehole					
B1	BANTANANI	20-1X-0001	718 946	1 518 140	93,212
B2	DIALACOTO	19-9X-0001	685 975	1 473 132	41,364
B3	BOUDOR BORDOR		623 971	1 540 170	33,133
B4	DAROU MANA	13-5X-0004	539 832	1 588 413	59,138
B5	BELEL TOUFFLE	13-2X-0002	550 171	1 645 732	19,080
B6	AGNAM CIVOL	08-2X-0004	643 560	1 768 720	7,400
B7	KANEL F4	08-6X-0011	694 685	1 713 056	25,120
B8	DIAGLE SINE	18-2X-0005	564 878	1 530 462	77,229
B9	SINTHIOU MALEME	19-1X-0003	616 249	1 528 300	14,910
Automatic water level meter installation well					
A1	BOYNGUEL BAMBA	15-7X-0001	723 111	1 559 478	74,892
A2	RANEROU		611 650	1 691 821	29,610
A3	FADIA KOUNDA	18-6X-0007	590 878	1 509 973	37,960

(2) Results of measurements using portable water level meter

An example of the fluctuations of groundwater levels observed at "B6 AGNAM CIVOL" is shown in the figure below and this is a typical pattern of seasonal groundwater level fluctuation in deep wells.

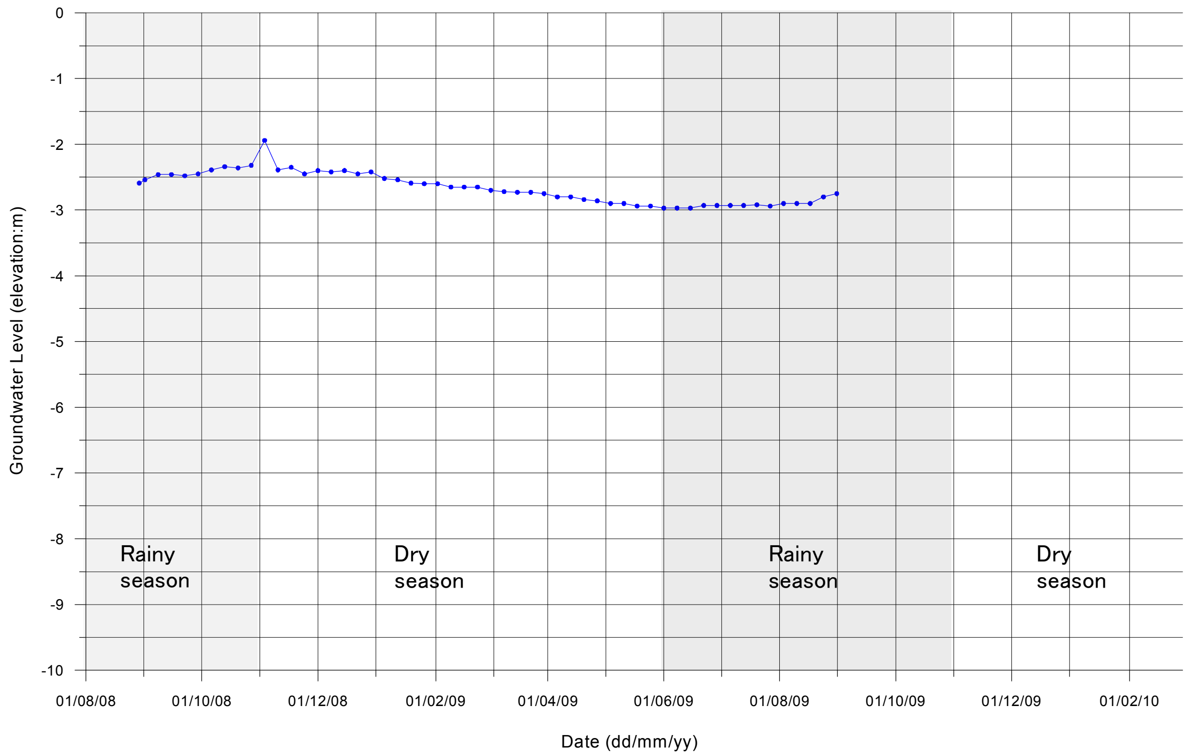


Figure 3-3-3 Example of seasonal fluctuations of groundwater levels (B6 AGNAM CIVOL)

3.3.4 River discharge measurement conducted in this project

In this project, river discharge measurements were executed at the points shown in Figure 3-3-4. The tendency in river discharge fluctuations can be described as follows.

- Northern part of Matam Region: The water levels rise rapidly and then lower gradually. (R2: Gourél Guéda, etc.)
- Western part of Matam and Tambacounda regions: River water appears only temporarily. (R11: Mana, etc.)
- Southwestern part of Tambacounda Region: River water flows continuously in the rainy season. (R14: Maka, etc.)
- Along boundary of basement and sedimentary areas: Water level fluctuations are large. In some areas, water levels rise gradually and lower relatively rapidly. (R28: Soutouta, etc.)

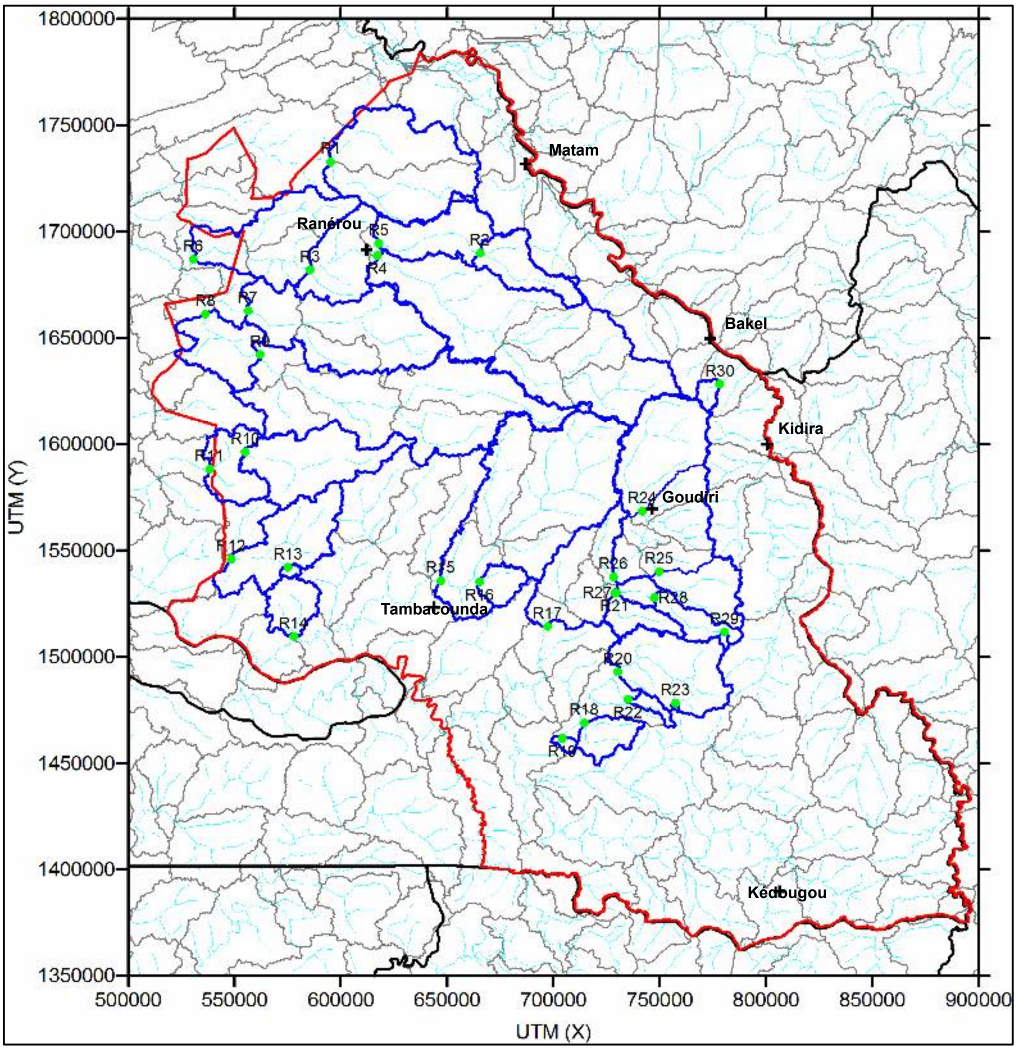


Figure 3-3-4 Location map of river discharge measurement stations

3.4 Evaluation of Water Potential

3.4.1 Contents of Water Resource Potential Evaluation

The water resource potential in this project area was examined from the following viewpoints based on the results of the hydrological investigation, geological investigation, hydrogeological investigation and geophysical survey and others.

- Surface waters: The characteristic of surface waters (river water) is clarified based on the results of the water use investigation, river discharge measurements and water balance analysis, and then the possibilities for water use are examined.
- Groundwater in sedimentary areas: The groundwater basin is evaluated based on the results of the water balance analysis and hydrogeological analysis. The groundwater flow simulation is used to evaluate the influence of groundwater development.
- Groundwater in basement rock areas: The examination is conducted on 1/200,000 geological maps based on the relation between the distribution of the fault and fracture zones and the thicknesses of the weathered zones clarified by existing data, geophysical survey and test drillings, and distribution and pump discharges of existing wells. Moreover, the possibilities for groundwater development are evaluated.

3.4.2 Estimation of Recharge

(1) Tank model
Runoff analysis using a tank model was adopted as the method of estimating recharge, which is one of the data necessary for calculating the simulation model. In this project, 4×4 type model with soil moisture structure shown in Figure 3-4-1 was constructed.

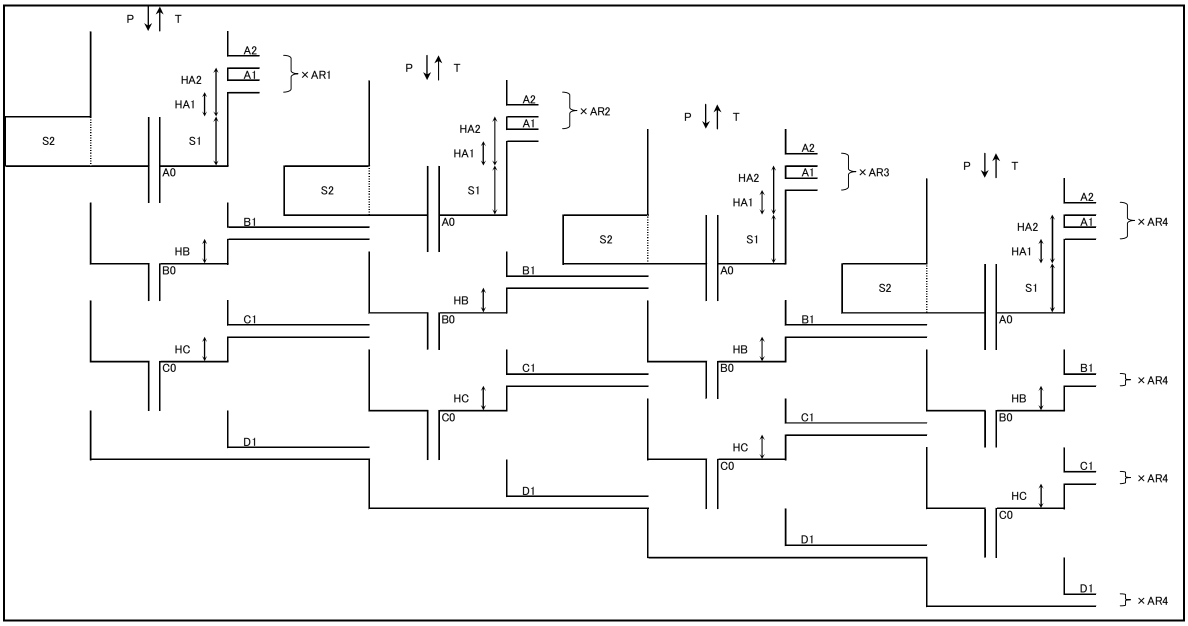
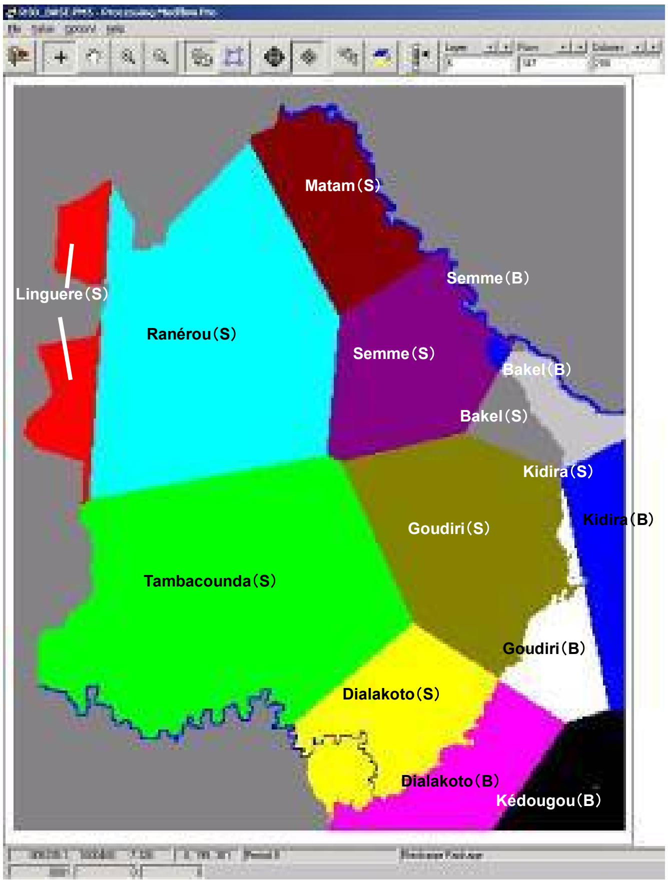


Figure 3-4-1 Tank model's structure（4×4 model）

The recharge was calculated for every 15 zones (Figure 3-4-2) that consist of combination of Thiessen polygon (refer to Section 3.2) and geology (sedimentary area and basement rock area). The tank model's parameter was verified by the following method.

- One river discharge station was selected in both sedimentary and basement rock areas where the drainage basin does not extend over two or more zones.
- The calculated values were compared with the observed values of river discharge at each station (Figures 3-4-3 and 3-4-4).



(S): Sedimentary area
(B): Basement rock area

Figure 3-4-2 Zoning for input of the monthly recharge

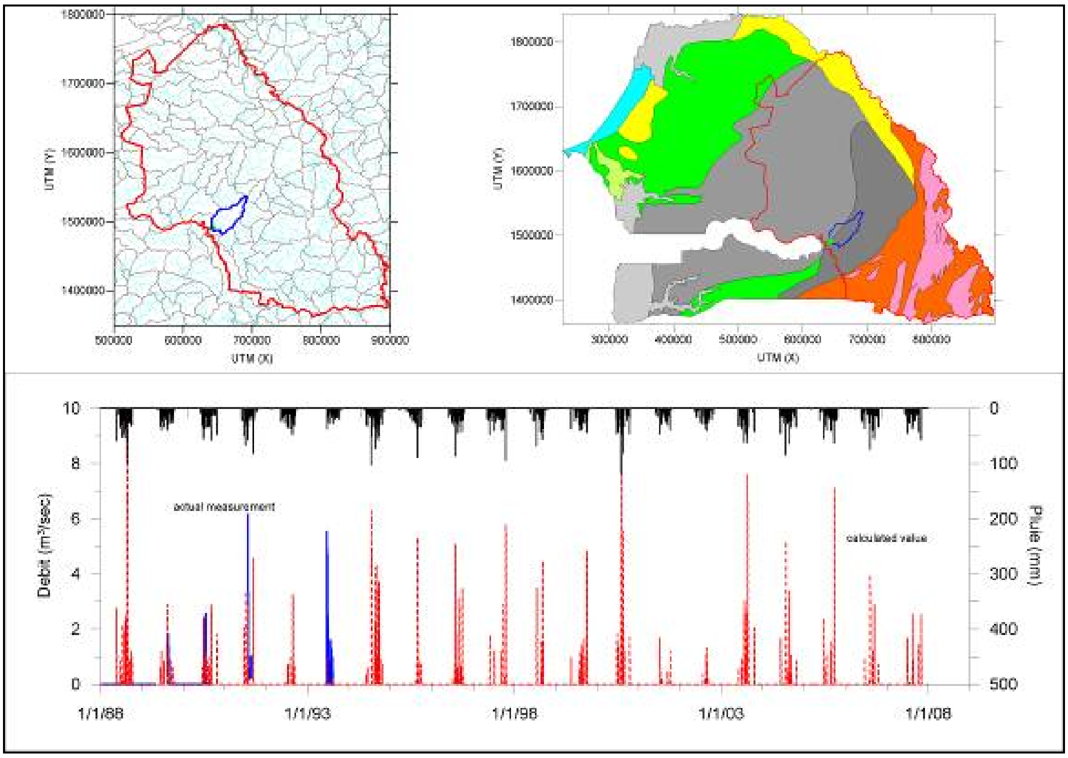


Figure 3-4-3 Tank model analysis in sedimentary area (Niaoule Tanou station)

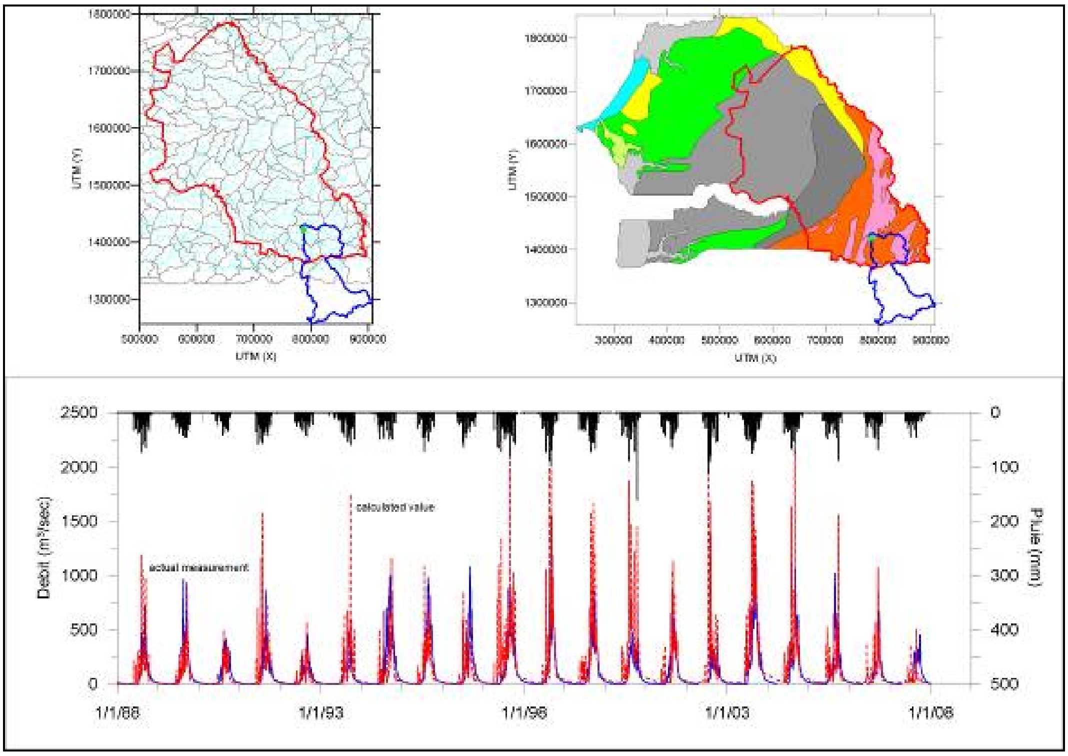


Figure 3-4-4 Tank model analysis in basement rock area (Mako station)

(2) Water balance

The water balance analysis was conducted using the tank model described above in each of the 15 zones. Though the calculations are made by unit of day, the water balance for each unit area on an average of 20 years from 1988 to 2007 is shown in Table 4-3-1. Moreover, the average value calculated by the tank model analysis has the following features.

- Precipitation: The average precipitation of 10 meteorological stations in the investigation area is from about 450 to 1 050mm.
- Actual evapotranspiration in sedimentary area: 91.5% to 96.8% of precipitation
- Actual evapotranspiration in basement rock area: 72.0% to 96.4% of precipitation
- River discharge in sedimentary area: 0.0% to 0.9% of precipitation
- River discharge in basement rock area: 0.1% to 26.6% of precipitation
- Recharge in sedimentary area: 2.9% to 7.3% of precipitation
- Recharge in basement rock area: 0.6% to 4.7% of precipitation

Table 4-3-1 Water balance for each unit area by tank model analysis
(average value of 20 years from 1988 to 2007)

Area	Precipitation	Actual evapotranspiration		River discharge		Recharge	
	(mm)	(mm)	(%)	(mm)	(%)	(mm)	(%)
Matam (Sediment)	440,6	403,3	91,5	3,9	0,9	32,0	7,3
Semme (Sediment)	498,1	463,2	93,0	1,5	0,3	32,8	6,6
Semme (Basement)	498,1	419,4	84,2	75,2	15,1	0,4	0,9
Ranérou (Sediment)	393,7	376,2	95,6	0,3	0,1	15,9	4,0
Bakel (Sediment)	501,1	477,4	95,3	0,1	0,0	22,3	4,3
Bakel (Basement)	501,1	342,6	86,3	64,1	12,8	3,8	0,8
Kidira (Sediment)	521,6	492,0	94,3	1,3	0,3	26,9	5,2
Kidira (Sediment)	521,6	451,4	86,5	65,7	12,6	4,1	0,8
Goudiri (Sediment)	548,6	531,1	96,8	0,1	0,0	15,9	2,9
Goudiri (Basement)	548,6	486,5	88,7	58,4	10,6	3,5	0,6
Tambacounda (Sediment)	682,2	632,9	92,8	0,3	0,0	46,9	6,9
Kédougou (Basement)	1 064,1	765,9	72,0	283,1	26,6	35,3	3,3

Area	Precipitation (mm)	Actual evapotranspiration (mm)	Actual evapotranspiration (%)	River discharge (mm)	River discharge (%)	Recharge (mm)	Recharge (%)
Linguere (Sediment)	301,8	290,7	96,4	0,4	0,1	9,5	3,2
Dialakoto (Sediment)	614,8	584,0	95,0	0,3	0,1	28,8	4,7
Dialakoto (Basement)	614,8	530,5	86,3	77,8	12,7	5,7	0,9

Though the ratio of actual evapotranspiration to precipitation is high as described above with 72%-97%, the actual evapotranspiration estimated in this project area is 290.7mm-765.9mm (average value of 20 years from 1988 through 2007). The value of 290.7mm-765.9mm is about 15%-43% of the amount of potential evapotranspiration (Table 3-4-2) and is not more excessive than the existing estimate cases in African regions. Conversely, this value shows that the water that should evapotranspirate and recharge is insufficient.

Table 3-4-2 Comparison between potential evapotranspiration (PET) and actual evapotranspiration (AET) for each unit area by tank model analysis (average value of 20 years from 1988 to 2007)

Area	Precipitation (mm)	PET (mm)	AET (mm)	AET Ratio to precipitation (%)	PET／AET (%)
Matam (Sediment)	440,6	1 930,9	403,3	91,5	20,9
Semme (Sediment)	498,1	1 930,9	463,2	93,0	24,0
Semme (Basement)	498,1	1 930,9	419,4	84,2	21,7
Ranérou (Sediment)	393,7	1 913,8	376,2	95,6	19,7
Bakel (Sediment)	501,1	1 927,8	477,4	95,3	24,8
Bakel (Basement)	501,1	1 927,8	342,6	86,3	22,4
Kidira (Sediment)	521,6	1 927,8	492,0	94,3	25,5
Kidira (Sediment)	521,6	1 927,8	451,4	86,5	23,4
Goudiri (Sediment)	548,6	1 930,5	531,1	96,8	27,5
Goudiri (Basement)	548,6	1 930,5	486,5	88,7	25,2
Tambacounda (Sediment)	682,2	1 915,9	632,9	92,8	33,0
Kédougou (Basement)	1 064,1	1 792,3	765,9	72,0	42,7
Linguere (Sediment)	301,8	1 913,8	290,7	96,4	15,2
Dialakoto (Sediment)	614,8	1 915,9	584,0	95,0	30,5
Dialakoto (Basement)	614,8	1 915,9	530,5	86,3	27,7

PET: potential evapotranspiration, AET: actual evapotranspiration

3.4.3 Estimation of groundwater discharge

(1) Estimation method of groundwater discharge
The groundwater discharge was estimated by the following policies and methods.

- Target is piped water supply facilities using groundwater sources.
- Calculation is by population supplied (village population + village population × 2.57)×unit supply rate.
- Unit supply rate is 35 liters / person with monthly changes.
- Growth rate of the village population is 0%.

(2) Discharge and recharge
Pumping rates of each piped water supply facility were calculated based on the policies and methods described above. The monthly discharge was totaled according to the aquifer and grid, and was used as input data for the simulation model.
The comparison of estimated discharge and groundwater recharge, calculated in the above paragraph, in the sedimentary area of this project, is shown in Table 3-4-3.

- Water supply facilities were constructed after 1990's. At the same time, however, a lot of facilities were ceased to be used. Therefore, there has not been a predominant increase in the amount of discharge.

- Over 20 years, the average amount of the discharge is only 0.6% of the recharge supplied from precipitation.
- The minimum ratio to recharge of discharge is 0.2% in 1988 and the maximum ratio is 7.0% in 2002.

Table 3-4-3 Recharge and discharge

Year	Recharge (m3/year)	Discharge (m3/year)						Discharge / Recharge
		Q aquifer	Co aquifer	Eo aquifer	Pa aquifer	Ma aquifer	Total	
1988	4 072 657 154	164 453	2 041 843	273 536	0	5 540 639	8 020 471	0,2%
1989	813 702 210	180 231	2 034 886	288 191	0	5 536 472	8 039 780	1,0%
1990	472 688 770	180 231	2 034 886	288 191	0	5 934 207	8 437 515	1,8%
1991	762 081 202	271 933	2 034 886	288 191	0	6 453 678	9 048 688	1,2%
1992	681 920 090	311 573	2 075 480	318 360	59 193	6 574 195	9 338 801	1,4%
1993	413 665 640	289 037	2 089 423	315 738	84 566	6 456 712	9 235 476	2,2%
1994	3 584 843 220	310 582	2 095 003	322 124	101 888	6 684 812	9 514 409	0,3%
1995	1 001 058 900	310 582	2 095 003	322 124	101 888	6 684 812	9 514 409	1,0%
1996	1 999 556 230	311 573	2 114 672	323 152	102 213	6 764 243	9 615 853	0,5%
1997	587 334 260	310 582	2 116 813	322 124	101 888	6 767 409	9 618 816	1,6%
1998	1 368 170 370	310 582	2 114 643	322 124	98 261	6 745 957	9 591 567	0,7%
1999	1 085 298 130	310 582	2 116 813	322 124	101 888	6 767 409	9 618 816	0,9%
2000	1 777 965 022	311 573	2 110 755	323 152	102 213	6 782 473	9 630 166	0,5%
2001	224 862 720	310 582	2 148 820	322 124	101 888	6 795 177	9 678 591	4,3%
2002	138 958 880	310 582	2 158 307	322 124	101 888	6 785 274	9 678 175	7,0%
2003	3 315 577 072	310 582	2 039 429	322 124	101 888	6 937 508	9 711 531	0,3%
2004	4 138 338 950	311 573	2 037 291	323 152	102 213	6 978 623	9 752 852	0,2%
2005	1 200 346 080	310 582	2 001 405	322 124	101 888	6 992 174	9 728 173	0,8%
2006	526 235 720	310 582	1 923 210	322 124	101 888	7 084 733	9 742 537	1,9%
2007	964 811 500	310 582	1 840 401	322 124	101 888	7 179 475	9 754 470	1,0%
Average	1 456 503 606	287 429	2 061 198	314 251	78 377	6 622 299	9 363 555	0,6%

3.4.4 Groundwater Model

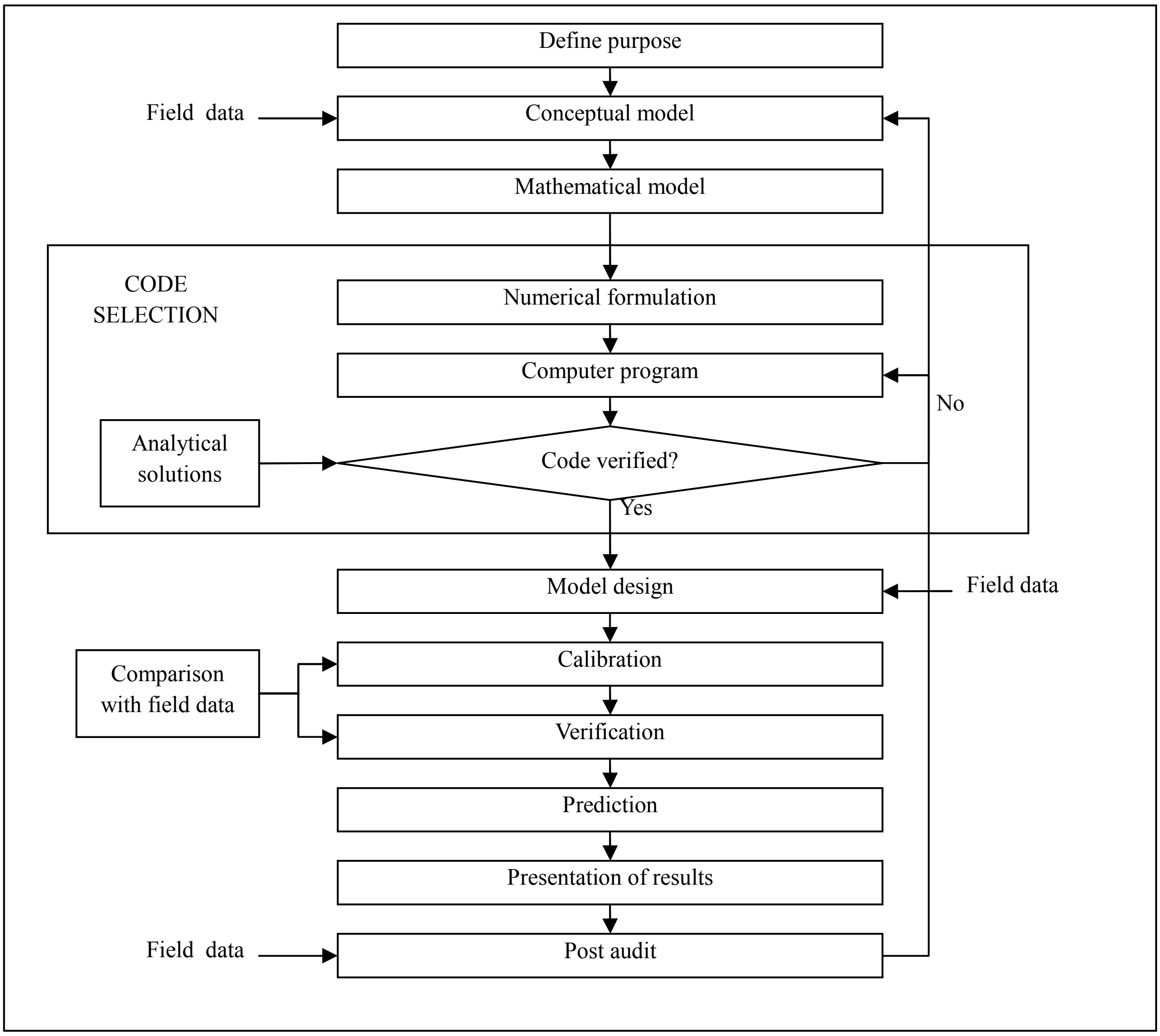
(1) Modeling procedure

Groundwater modeling was conducted according to the flowchart shown in Figure 3-4-5. Modeling executed by this project consists of “code selection”, “model design”, “calibration and verification” and “prediction”. Generally, a post audit is conducted several years after the model period is finished, and after that the model is redesigned about once every 10 years.

Moreover, the following matters are included in the purpose of the simulation analysis of this project.

- Selection of region where groundwater can be developed (extraction of region where groundwater development is difficult).
- Selection of an aquifer where groundwater development is possible.

In this project, the simulation analysis was continued while examining the validity of the water source position and the aquifer planned with M/P since the stage of the prediction analysis.



(Source: Applied groundwater modeling, p7, Anderson M.P. and W. W. Woessner, 1992)

Figure 3-4-5 Procedure for model application

(2) Adopted code

The MODFLOW code was adopted for the groundwater flow simulation analysis. The MODFLOW code is an analytical code used worldwide and many software for I/O is developed. In this project, the analysis was conducted using integrated software "Processing Modflow Pro".

MODFLOW is a 3D groundwater flow analysis code developed by US Geological Survey and the 3D groundwater flow expressed by the partial differential equation is solved by the finite differences method.

(3) Data used in this model

The following table lists the items required to build a groundwater model and data used in this project.

Table 3-4-4 Data used for groundwater model

Item		Used data
Hydrogeological structure		Based on the well columns prepared from the drilling reports of DHR, DGPRE,and others, as well as existing geological and geophysical reports, the hydrogeological structure analysis was conducted. Also, the model was corrected based on the geophysical survey and test drilling results.
Hydrogeological parameter		Transmissivity (hydraulic conductivity) distribution was estimated based on the well drilling reports of DHR, DGPRE and others . The initial values of the coefficient of storage, effective porosity and specific yield use general values estimated from the face of the aquifer.
Recharge		Dry land type (non-humid type) tank model was prepared, and the recharge for 20 years from 1988 to 2007 was estimated. The data used for the tank model is as follows.
	Meteorological data (precipitation and temperature)	Observation data from 1988 to 2007 of Météorologie Nationale and others were used.
	Data for verification	River discharge data measured by DGPRE were used.
Discharge		The discharge is estimated based on operational situation of existing water supply facilities, and demographics of 2002.
Initial head		Before the period of verification (from January 1988 to December 2007), long-term transient calculation is conducted and this result is used as initial head values.
Boundary condition		The boundary conditions were set based on river discharge observation data and groundwater level observation data of the river neighborhood.
Data for verification		Groundwater level monitoring data of DGPRE were used.

(4) Model structure

A plane grid of the wide area 3D model was set to cover the entire sedimentary area of this project as shown in Figure 3-4-6. The model grid was based on zone 28 in UTM coordinate system of WGS84 and each grid size is 1km x 1km (X direction: 301 grids, Y direction: 367 grids).

Regarding the section structure, this wide area 3D model covers the entire groundwater basin within Tambacounda and Matam regions in the depth direction and reflects the hydrogeological conditions down to the base of the groundwater basin (bottom of the Ma aquifer). The aquifers can be divided into five types, and along with the basement rock layer, they compose the adopted six-layer model.

- Quaternary aquifer (Ma aquifer)
- Continental terminal / Oligo-Miocene aquifer (Co aquifer)
- Eocene aquifer (Eo aquifer)
- Paleocene aquifer (Pa aquifer)
- Mastrichtian aquifer (Ma aquifer)
- Basement rocks

Moreover, it is necessary to set a boundary condition that takes into consideration the hydrogeological conditions in the simulation model. The closed boundary and general head boundary are set in this model.

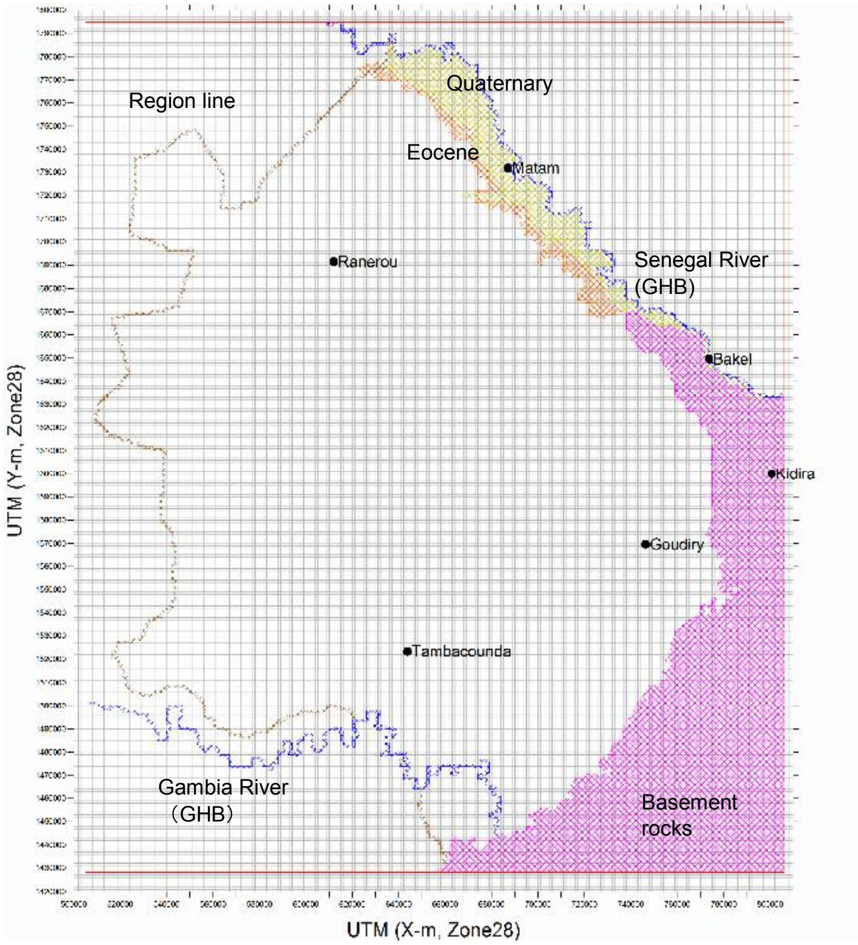


Figure 3-4-6 Simulation analysis area (Grid design)

(5) Results of calibrations

After the above-described initial hydraulic head (Section 3.2.4) was inputted into each model layer, the monthly recharge and monthly pump discharge data of 240 months from January 1988 to December 2007 were inputted and the verification calculation was conducted. The accuracy of the model was verified by comparing the measurements of groundwater level fluctuations at DGPRE monitoring wells with the calculated groundwater level fluctuations.

Moreover, the calculation results of the exchange of the river water of the Senegal River and groundwater for the verification period is shown in Figures 3-4-7 and 3-4-8 (blue shows the inflow from the river to groundwater, and red shows the outflow from groundwater to the river). The characteristics of the exchange of both are described as follows.

- The inflow from the Senegal River to groundwater is generated in both Q and Ma aquifers during the rainy season (especially, end of the rainy season). Meanwhile, the outflow of groundwater to the Senegal River is generated during the dry season.
- Over 20 years, an average of about 30 million m3/year outflow to the river from the Q aquifer is estimated. Meanwhile, about 13.5 million m3/year inflow to the Ma aquifer from the river is estimated.
- Outflow from the Q aquifer is 6.75 million m3/year (1994) to 52 million m3/year (2004).
- Outflow from the Ma aquifer is 30 million m3/year in 2004. Meanwhile, 100 million m3/year inflow to the Ma aquifer is estimated in 1994.

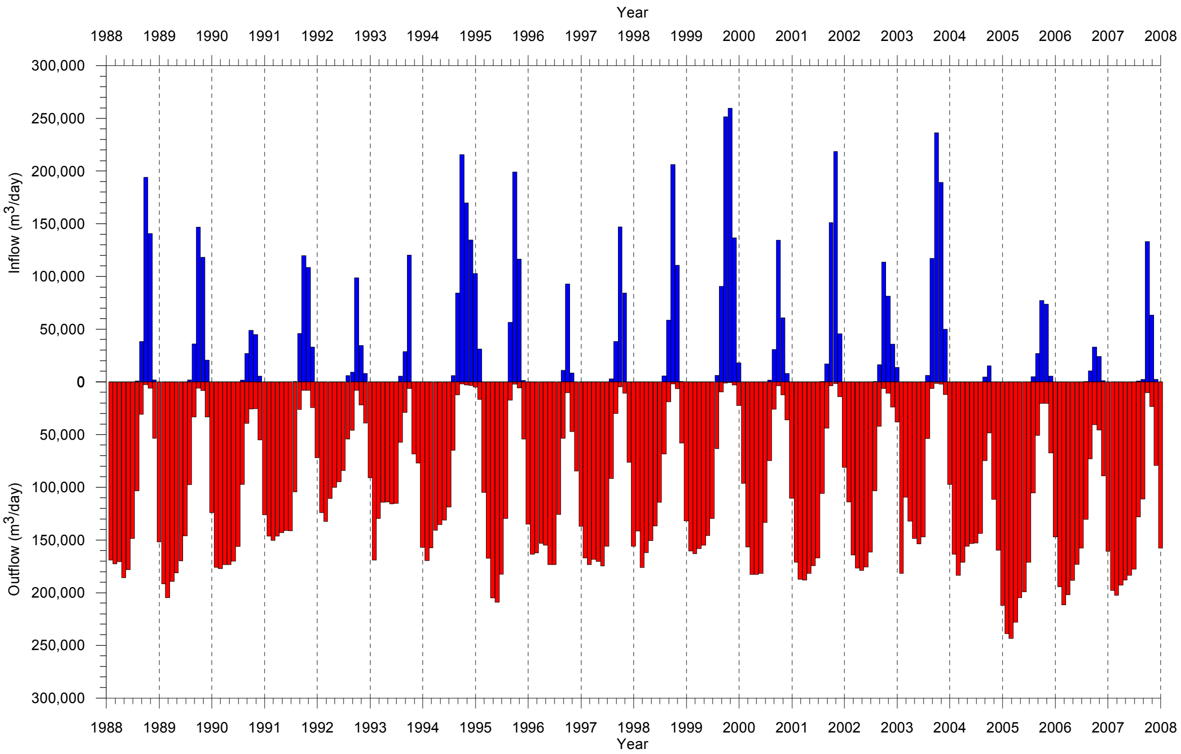


Figure 3-4-7 Inflow and outflow between Senegal River and groundwater (Q aquifer)

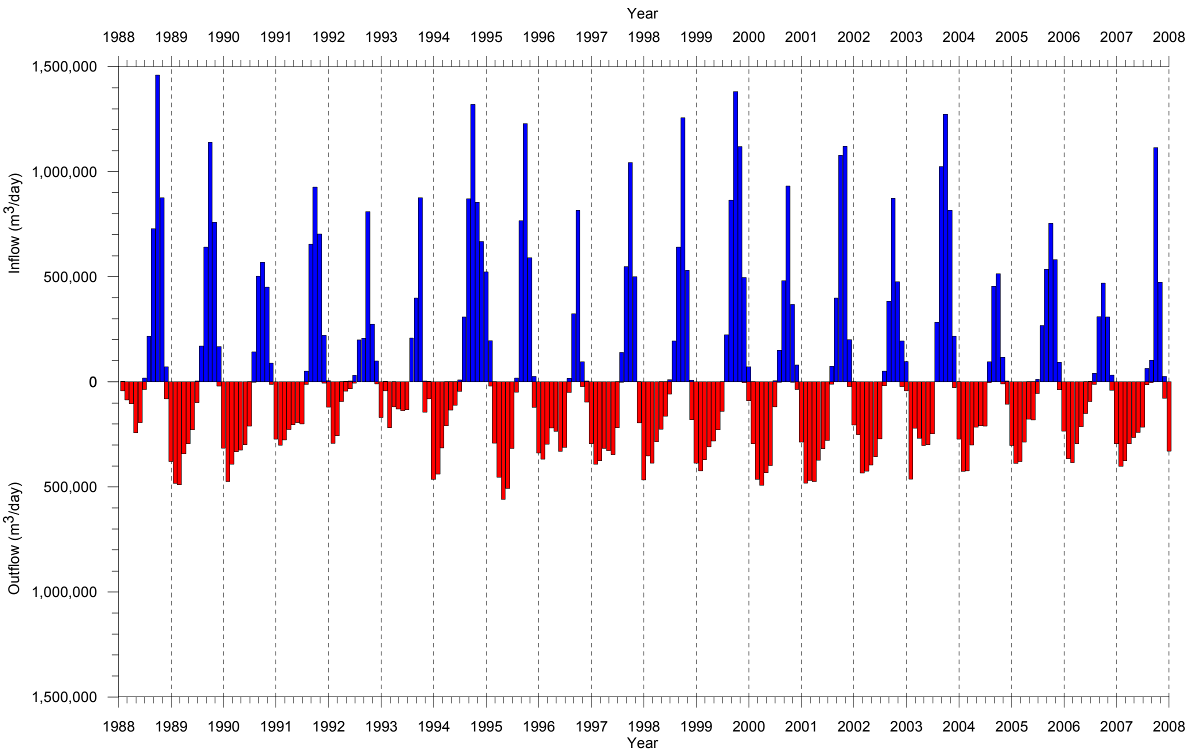


Figure 3-4-8 Inflow and outflow between Senegal River and groundwater (Ma aquifer)

(6) Vulnerability analysis

The following two scenarios were planned to assess the hydrogeological vulnerability and differences in groundwater drawdowns were calculated in the study area.

① Fluctuations of recharge

② Fluctuations of pump discharge

When the predictive calculation in accordance with the Master Plan described in Chapter 8 was conducted, these data were used for setting the intake aquifer of each water supply facility.

3.4.5 Evaluation in Sedimentary Area

The sedimentary area in the target area is divided into 5 zones as shown in Figure 3-4-9 according to the hydrogeological structure, groundwater level (groundwater flow), vulnerability and other factors. And the hydrogeological characteristics of each zone are arranged in Table 3-4-5.

This zoning is supported by the results of the cluster analysis of main ions (Ca, Mg, Na, K, Cl, HCO3, SO4) of the Mastrichtian aquifer's groundwater.

Moreover, aquifer thicknesses, groundwater level and other distribution parameters in each village located in the sedimentary area were examined and arranged.

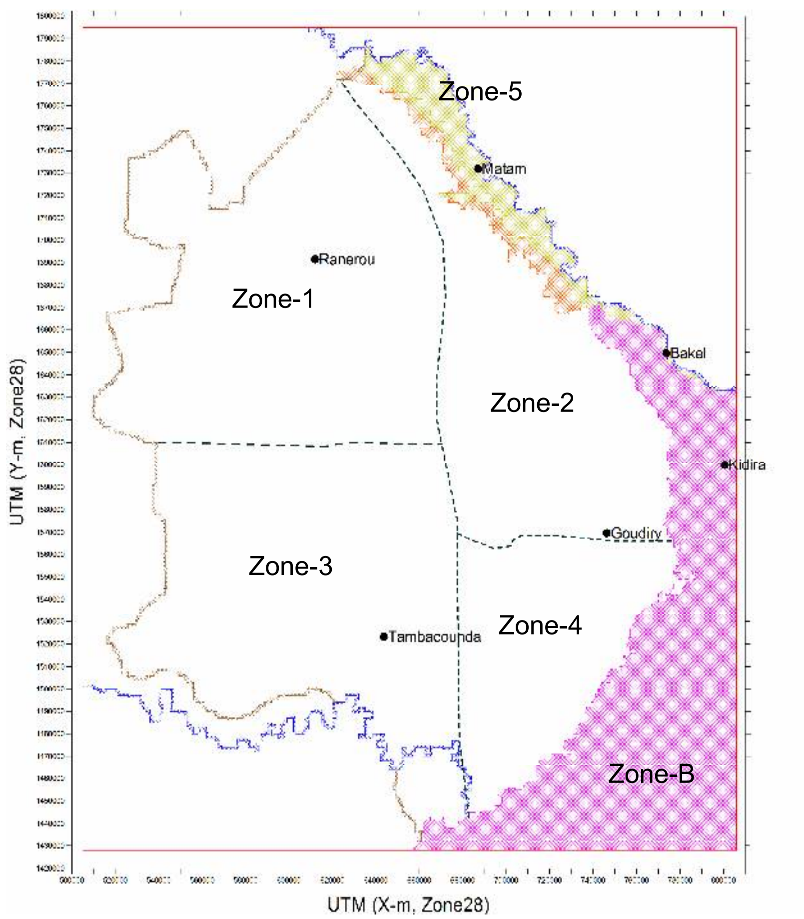


Figure 3-4-9 Zoning of sedimentary area

Table 3-4-5 Zoning and hydrogeological characteristics

	Zone-1	Zone-2	Zone-3	Zone-4	Zone-5
Q aquifer (Fluvial deposit)	–	–	–	–	Fluctuation of groundwater level is relatively high due to the recharge from the Senegal River during the rainy season. The identification of changes of thicknesses and facies is important.
Co aquifer (partially contains Quaternary sediments .)	There are some areas where groundwater intake is possible, but a major development is not suitable as they are easily influenced by changes in recharge and discharge.	As the thicknesses are thin, the possibilities for dry wells are high. Partial development of perched groundwater is possible.	The highest potential zone of Co aquifer.	There are areas where groundwater intake is possible in the valleys of the basal surface. However, possible areas are limited as compared to Zone 3.	–
Eo aquifer	Groundwater exists in some facies. However, the possibilities for steady water-intake are low.	As the thicknesses are thin, the possibilities for dry wells are high. Partial development of perched groundwater is possible.	It is possible to pump up groundwater in some parts of high permeability facies and at collecting points of groundwater.	It is possible to pump up groundwater in some parts of high permeability facies and at collecting points of groundwater. However, possible areas are limited as compared to Zone 3.	–
Pa aquifer	Groundwater exists in some places by facies. However, there is a high possibility that steady water-intake is not possible.	Groundwater exists in some places. However, there is a high possibility that steady water-intake is not possible.	It is possible to pump up groundwater in some parts of high permeability facies and at collecting points of groundwater.	It is possible to pump up groundwater in some parts of high permeability facies and at collecting points of groundwater. However, possible areas are limited as compared to Zone 3.	–
Ma aquifer	Though this is the main aquifer in this zone, capacity is lower than that of Zone 3. However, the depth of the well is shallower than that of Zone-3.	The influence by fluctuations of recharge and discharge is higher as compared to that of other zones.	Presents the highest potential. However, the development depths become deeper	Influenced by fluctuations of recharge and discharge in the vicinity of the basement rocks. So planner needs to confirm that the thickness of the aquifer is sufficient.	Becomes thicker downstream. There is no possibility of an intake layer near Kidira-Bakel because it is not so thick.

3.4.6 Evaluation in Basement Rock Areas

Generally, it is important to comprehend the following items for groundwater development in basement rock areas.

- Hydrogeological structure (fault, fracture zone, etc.)
- Deep weathered zone
- Distribution of dikes and veins

Regarding basement rock areas, the groundwater potential division as shown in Table 3-4-6 is analyzed from the relation between geology and the geological structure, and the discharges of existing wells.
Moreover, the region along large and medium size rivers where the sedimentary deposit (Q aquifer) is thickly distributed and has a hydrogeological condition similar to Zone-5 in Table 3-4-5.

Table 3-4-6 Geology and groundwater potential in basement rock areas

Surface geology	Groundwater Potential	
	High	Possible
Cambrian sedimentary rocks	• Distribution of basaltic rocks with faults and fractures • Distribution of pelitic rocks with dense fractures • (Distribution of quartz veins)	• Distribution of faults and fractures • Distribution of quartz veins • The underlying metamorphic rock is the main aquifer around Kidira-Bakel area.
Cambrian volcanic rocks (Andesite)		• Distribution of faults and fractures
Cambrian metamorphic rock (Schist, Quartzite)	• Distribution of basaltic rocks with faults and fractures • (Distribution of quartz veins)	• Distribution of faults and fractures • Distribution of quartz veins
Dolerite	• Distribution of faults and fractures	• Distribution of small faults and fractures
Birrimien（Schist, Quartzite, Greywacke, Conglomerate）	• Distribution of basaltic rocks with faults and fractures • (Distribution of quartz veins）	• Distribution of faults and fractures • Distribution of quartz veins
Cipolins		• Distribution of faults and fractures
Basaltic rocks	• Distribution of faults and fractures	• Distribution of small faults and fractures
Andesitic rocks		• Distribution of faults and fractures
Amphibolite		• Distribution of faults and fractures
Granitic Rocks (excluding the syntectogenic)		• Distribution of faults and fractures • Distribution of quartz veins • Distribution of pegmatite veins
Granitic Rocks (Syntectogenic)	• Deep weathering in coarse granite • Distribution of dikes in coarse granite • Distribution of basic rocks with faults and fractures	• Distribution of faults and fractures • Distribution of quartz veins • Distribution of pegmatite veins

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Sanitation

4.7 Summary of Sanitation Master Plan

4.7.1 Scope of Sanitation Master Plan

In this Master Plan, it was decided to establish a policy to improve the access rate to improved individual sanitation facilities as part of the sanitation project package for rural areas as recommended in the PEPAM framework.

In PEPAM, the technical options for improved water supply facilities and sanitation facilities were categorized as shown below. The rate of access to sanitation facilities was defined using the number of residents who will have access to "improved sanitation facilities" shown in Table 4-7-1 below.

Table 4-7-1 Classification of improved and unimproved water supply facilities and sanitation facilities[1]

	Improved facilities	Unimproved facilities
Water supply system	• Water supply to individual households through house connections • Public water faucets • Deep wells with handpumps • Protected (improved) shallow wells • Protected springs • Rainwater harvesters	• Unprotected shallow wells • Unprotected springs • Purchase from water vendors • Bottled water (unprotected and unprocessed)* • Unprocessed water supplied directly from water tankers
	Improved facilities	Unimproved facilities
Sanitation facilities	• Sewerage pipelines connected to public sewerage lines • Wastewater treatment facilities connected to septic tanks • Flush toilets • Dry system toilets • VIP toilets with ventilation	• Human waste tub toilets** • Unprotected open pit toilets • Public lavatories using the above systems

* Categorized as unimproved facilities because of poor quality and insufficient quantity.

** Human waste is collected in tubs or buckets and thrown away by manual labor.

In addition, in this project, the specifications of the improved sanitation facilities were categorized as shown in Table 4-7-2 below.[2]

Table 4-7-2 Specifications of sanitation facilities in PEPAM

1. Urban public sanitation facilities (Assainissement Collectif) Sewerage pipeline is connected to each household. Composed of a pipeline to dispose wastewater, removal facilities and water purification facilities.
2. Individual sanitation facilities (Assainissement autonom/sur site) i. Household sanitation facilities (Assainissement Individual) Household toilets and rainwater/wastewater treatment facilities • Desirable facilities for urban household sanitation: Combination-type septic tanks, toilets with ventilated decomposition tanks or flush toilets, wastewater treatment facilities connected to septic tanks, combined wastewater treatment facilities connected to decomposition tanks

[1]Source: "Elaboration d'un document de stratégie pour la réalisation à l'horizon 2015 des objectifs du millénaire pour le développement, Volume 1: ETAT DES LIEUX Rapport définitive," p46; Translated into Japanesethen into English by the survey team.
Obtained in October 2008 and used as a source for the Progress Report 2. In the new version, translation was performed again in order to make changes in word usage. (In the previous version, "traditionnelle (traditional)" was used but the word was changed to "non-amélioré (unimproved)" or "Non protégé (unprotected)" and also notes were added.)

[2]Source: "Elaboration d'un document de stratégie pour la réalisation à l'horizon 2015 des objectifs du millénaire pour le développement, Volume 1: ETAT DES LIEUX Rapport définitive"

• Desirable facilities for rural household sanitation: Improved ventilated toilets or flush toilets, or promotion of wastewater treatment facilities (decomposition tanks/septic tanks) ii. Public sanitation facilities (Assainissement des zones publiques) Toilets in public areas where there is a large volume of human traffic (markets, hospitals, schools, religious institutions, roadside stations, etc.) and rainwater/wastewater treatment facilities
3. Autonomous public sanitation facilities (Assainissement Semi-Collectif) These are facilities to collect both human waste and domestic wastewater for treatment using small-scale treatment facilities such as a small-diameter underground pipelines and decomposition tanks or septic tanks. These facilities are conditional on autonomous operation by their owners (community or village).

4.7.2 Targeted Goals

This rural sanitation master plan applies the study's basic policy so that consideration on rural sanitation programme implementation always accompanies with water supply project. And this principle makes contents of the project established in this Master Plan are divided in to three phase as short term (2010-2015), middle term(2016-2021), and long term (2022-2027) as well as the goals are defined uniformly for the 3 phases as shown in Table 4-7-3 below. In this sanitation development component of Master Plan, those three regions treated as the same condition and applied 3.7% of annual increase rate in whole target area.

Table 4-7-3 Goals for sanitary environment improvement in target areas

Period Region	Target year 2015 Short term	Target year 2021 Middle term	Target year 2027 Long term
National revel	63%	81%	91%
Tambacounda	60%	80%	90%
Kédougou	55%	77%	88%
Matam	56%	78%	89%

source : PEPAM-UC/DAR/JICA

4.7.3 Contents of Sanitation Master Plan

The proposed sanitation master plan is composed of three elements: 1) construction of sanitation facilities; 2) proper application of the sanitation concept and health and sanitation knowledge; and 3) establishment of a sustainable operation system in the village. The entire system will be called the rural sanitation system and plans will be made combining the following components.
The minimum unit applied in this planning process is the village.

Table 4-7-4 Components of rural sanitation system

Component 1	Construction of household/public sanitation facilities
Component 2	Activities to identify local resources (human, budget, existing approach, natural resource…)
Component 3	Activities to improve capabilities of human resources Development (training) of rural sanitation education staff (mainly women[3]) Development (training) of technician and staff of ASUFOR or CBO related to amelioration of sanitation condition in villages
Component 4	Implementation of activities to improve sanitation concept within village
Component 5	Establishment of sustainable implementation system (including monitoring and evaluation)
Component 6	Other activities (to prevent open-air defecation)

[3] In the target area, they are called Relais féminin.

Table 4-8-3 Priorities when installing public sanitation facilities

Priority	1st/ 2nd (same priority)	1st/ 2nd (same priority)	3rd	4th
Location	Schools	Schools	Religious institutions	Public spaces
Specifications for installation	2 facilities per location, 1 each for men and women		1 per location	Villages with more than 500 villagers 1 each for men and women per village

In previous projects that have been implemented under the PEPAM framework so far, it was recommended to construct public toilets at markets and roadside stations for use by the general public coming from outside the village. It is reported, however, that in many cases the constructed toilets are left unattended, poorly cleaned and carelessly used and the maintenance issue remains unsolved. In this Master Plan, however, it is planned to develop sanitation facilities at important public institutions in the village where the users can be identified to a certain extent in order to improve the effectiveness of the project. Also, in setting the priorities, the policy will be to select the target institutions by confirming that there are both users and maintenance staff on a daily basis. When it is determined to proceed with this project, if there are any poor households in the village that are unable to install a household toilet, a review will be conducted on installation of toilets in public space in the village as shown in the above column for the 4th priority.

4.8.3 Sanitation Project to be Implemented Independently

If any sanitation facilities development project is implemented independently (in which all or part of the construction costs are provided), the target villages will be selected according to the above flow so that sanitary habits can be established in the villages and sustainable operation of the facilities can be ensured comparable to the input.

Although the project will be implemented village by village, it should be the policy to review the project over a wider scope to obtain synergy between villages, for example, by combining neighboring villages that belong to the same CR or villages with the same social and cultural backgrounds as well as aggregating areas under the charge of one ASUFOR for the water supply into one greater area. Also, it should be the policy to establish a monitoring system so that the local administrative bodies and DAR can see how the access rate is improved.

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Chapter 7 Operation and Maintenance Plan

7.1 Consignment of Maintenance to Private Sector

7.1.1 Policy on Consignment of Maintenance to Private Sector

According to the sector policy document of 2005 (Lettre de politique sectorielle de l'hydraulique et de l'assainissement en milieu urbain et rural, June 2005), which was agreed by 4 Ministries, the maintenance activities were officially noted to be consigned to a private sector by DEM. The plan for structural reform of DEM after the consignment has been already established (though the report has not been disclosed yet). However, the capacity for execution of maintenance activities by the private companies has been questioned in the central area of Senegal, where the consignment to private sector was planned to be commenced earlier than the other areas of Senegal, resulting in a situation where no company was selected for the consignment.

In the target area, there are comparatively worse conditions than the central area, such as aging facilities, delay of establishment of ASUFORs, low density of facilities, and absence of private companies capable of maintenance consignment within the target area, and therefore, it is hard to realize the consignment. Without implementation of any projects in the future to overcome these challenges, the difference between the central and the target area shall be more obvious.

7.1.2 Promotion Period for Consignment of Maintenance Activities to Private Sector

Promotion of consignment to the private sector in Senegal is supposed to be commenced from the central area of Senegal. It is desirable to implement the consignment to the private sector in the target area using model cases or lessons learnt in the central area. Therefore, promotion of the consignment to the private sector will be described in the mid-term plan (2016-2021).

On the other hand, in comparison with the preceded areas, the target area suffers from such situations as, 1) delay of transition into ASUFOR, and 2) breakdowns and severe deteriorations of most facilities. Therefore, conditions of the consignment to the private sector (rehabilitation of facilities, exchange of equipments, establishment of ASUFORs, and installation of meters for metered billing) shall be prepared as much as possible during the period of the short term plan.

7.1.3 Project Plan

(1) Preparation Stage (Short Term Plan 2011 - 2015)
As a preparation stage for promotion of the consignment to the private sector, such activities are planned as, 1) transition of the water management committees into ASUFORs, and 2) resolution of issues of facilities rehabilitation before 2015.

(2) Implementation Stage (Mid-term Plan 2016 - 2022)
There is no plan for financing except for an expression of support to private sector consignment by BAD. Therefore, DHR and DEM shall raise funds in order to promote the following activities.

- Formulation of the Terms of Reference (TOR) for the consignment to the private sector, and selection of the target villages
- Supervisory works of the tender for the consignment to the private sector
- Resolution of the issues of the contract (rehabilitation of facilities, exchange of equipments and establishment of ASUFORs)
- Support of SM/BPF for strengthening its supervisory works of consignment to the private sector
- Monitoring of the consignment to the private sector for a year after commencement

The above activities are the standard works for promoting the consignment to the private sector.

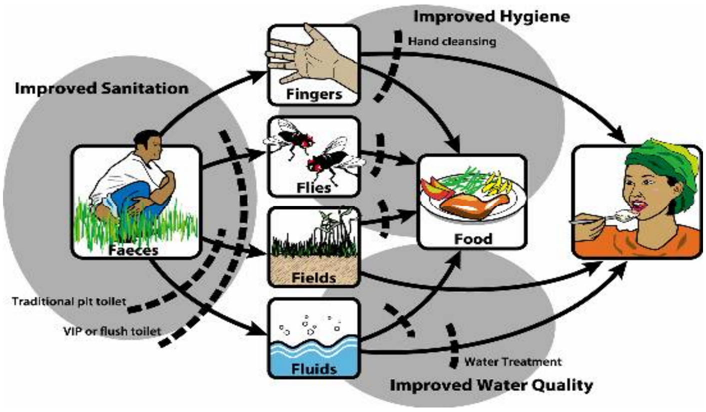

Figure on the left shows the contamination route of oral-fecal diseases that are transmitted by oral route; it also shows the related prevented measures along with the water, hygiene and environment relation.

Legend
Black lines: contamination routes
Doted lines: Barrier against contamination by diseases
Grey Zones: Scope of the contamination barrier

Figure 8-1-1 Fi-diagram and relations between water, sanitation facilities and health notions[2]

Water supply development projects and sanitation facilities development projects are two key mainstays to promote living conditions' improvement in rural villages. In this present master plan, the four measures above mentioned will be applied in order to overcome the issues in the project's target regions.

8.2 Issues relating to the improvement of sanitation conditions

(1) Issues

Under the current sanitation status in the target region, the issues to be overcome may be classified into the two major categories below:

Current status		Causes
• Inappropriate defacation and attitude to human excreta based on the low accessibility of improved latrines. • Incompleate drainage based on the non-introdution of domestic wastewater treatment system • Lack of preventive activities against water related deseas such as utilization of in-purified water from shallow wells and river. • Lack of public sanitation service	⟷	• Low priority because of poor awareness on hygiene and health • Worse saniataion environment caused by lack of information and knowledge on it. • Lack of future plans for amelioration of the environment • Differences between regarding important issues and competence of service providers, as well as the speed of providing basic social infrustructures.

(2) Step of improvement for the sanitation conditions

Taking into account the above conditions in the target region, a stepwise rank[3] of the sanitation related issues could be shown as follows:

First step: Developing the basic hygiene environment

・ Definition : Step where it is necessary to keep away the village people everyday life from human and livestock excreta and prevent water borne diseases resulting from inappropriate drainage of wastewater.
・ Situation of the target region : Almost the entire target region are on this firsst step.
・ PEPAM Framework : The package is standardized and its implementation is recommended.

Second step: Developing the health environment in community area

・ Definition : A certain number of households already experiences to deal with some hygiene and saniation related issues. This Step is aimed at avoiding water sources pollution caused by the

[2]Source : Developed by the survey team referring to a revision of the Windbland U. & Daddly Diagram, 1997

[3]The related concepts for the establishment of a health environment and improvement of the living environment are often depicted by the image of a staircase that one has to go up step by step (health scale). On the basis of those concepts, it was intended to undertake a stepwise classification of the current situation in order to catch it up in this step of the Master plan.

environmental degradation, such as inappropriate treatment of the various types of waste water, rainwater, domestic wastewater and filthy water also by disposed waste in the villages and in the entire community, in order to prevent an outburst and formation of microbe nests as well as pathogens.

- Status of the target region : A certain number of villages are on this step.
- PEPAM Framework : Along with household level measures, community level measures are recommended for rain water drainage in the area and for improving the health environment. Even if the facilities are defined as public sanitation facilities, the criteria relating to the required capacities and nature for those applying services providers are not clearly defined yet.

Third step: Developping environment imporovement in the area

Definition : In this step a comprehensive and more advance development of public sanitation facilities, as compared to the above two steps is necessary. At the village level some disparities are observed ; a few of wealthier people have latrines or septic tanks for wastewater drainage and this situation is one cause to verify the measures to be taken inside one village. In this step we need to another study for sewage connection with septic tanks and wastewater treatment facilities (including ditch deposits) and large waste treatment plants that may possibly operated in the target region.

- Situation of the target region: These are very few, those grand villages that might become Rural Community County towns[4] are on this step.
- PEPAM Framework: Situation on this step has been beyond the category of rural sanitation development. However, the consideration on the development for semi-urban public sanitation service is urgently necessary.

In the three target regions, most of sites still remain at the first step where it is still necessary to develop basic health environment. However, the communes, commercial hub, transportation hub along the national road, or grand villages along with the Senegal River (more than 5000 population) are on the third steps.

8.3 Basic Rural Sanitation Plan

8.3.1 Designing the basic rural sanitation plan

In order to sustainably improve the living condition in the villages, the related orientations for the sanitation development projects (introducing sanitation systems) will be planned reflecting the mutual relation between water, sanitation and health.

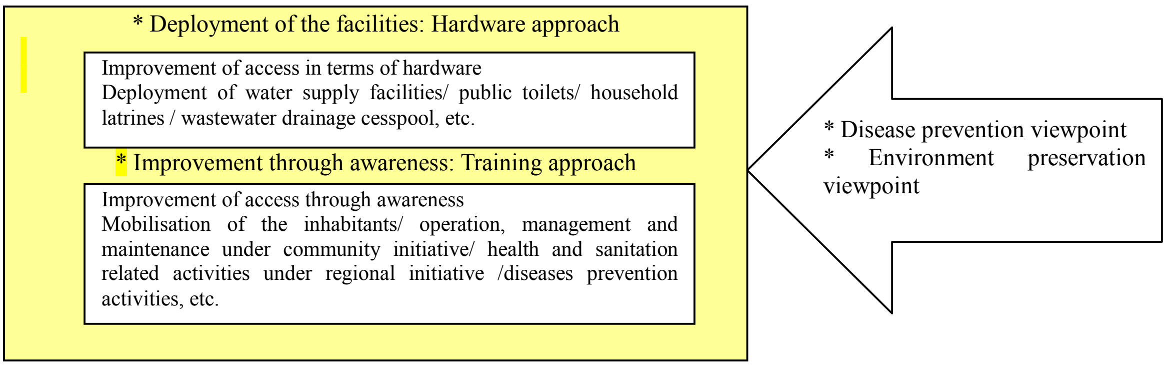

Figure 8-3-1 Conceptual Scheme of sustainable environment preservation

The issues to be considered during the study on the orientations are as follows:

- To increase the number of household latrines, it is indispensable to promote a health and hygiene notions and willingness to improve the environment trough building their ownership of the facilities. The Rural Sanitation Department (DAR) also initiated an approach called as

[4] Rural Community county town

Community-Lead Total Sanitation (CLTS) that particularly stresses the importance of enhancing hygiene notions; in particular the awareness on ora-feces transmitted diseases in order to keep away the villages from excreta. The study on the introduction of such activities is shown herein in section 8.3.4 (4) in Chapter 8 of Main Report.

- To promote a comprehensive hygiene and health education at the village and regional levels, it is desirable to provide with training the community based extension worker (relais) that are the main executing agents of health education activities within the village, and support village level health education activities as well as to train the technicians (masons)[5] who construct the facilities; and on the other hand, combining creation of the system with promoting community participation is indispensable.
- Providing support the Communaute Rurals (CR) that are responsible for establishing Local Water supply and sanitation plans (PLHA[6]), in order to improve information management functions withinis also necessary.
- In order to correctly use, properly manage and maintain the sanitation facilities, village population (users) will be required to bear about 10%[7]of the latrines construction costs. Moreover, it will be difficult for the most disadvantaged village people to afford those 10%, so we propose the establishment of a micro-credit system using the funds or savings of the community based organization (CBO) such as the ASUFOR.

8.3.2 Measures taken in the Master Plan towards sanitation facilities

The status of public and household sanitation facilities deployment, are shown below along with the measures proposed in the present project.

Table 8-3-1 Current status of public sanitation facilities and measures proposed by this project

Specifications	Proposed number of facilities	Measures suggested by the present project
VIP latrines with open ditch	About 90%	Confirming the lapse of time since construction and establishment of a management and maintenance system is indispensable. [Issues to be considered] The existing latrines in schools and health centers in the target region are mostly open ditch VIP latrines. Consequently, in most case the lifespan of the latrines is limited to the capacity of the ditch. We already experienced overflow in some areas and it is quite difficult to keep on using it. Moreover latrines are not provided with lavatories. Such situation is observed in most of the sites in the target region. Consequently, we are suggesting constructing new latrines reflecting the level of priority.
VIP latrine with dual ditch	About 10%	
TCM	Very few	

Remark: As for the proportion of household, the baseline survey results conducted in 2009 for the selection of the priority sites and the results of the baseline qualitative survey were added.

Table 8-3-2 Current status of household sanitation facilities and measures proposed by this Project

Specifications	Proposed number of facilities	Measures taken by the present project
Simple traditional hole	about 80%	Does not match with ongoing sanitation facilities standards and are not considered as existing facilities. Construction of new facilities. [Issues to be considered] Consider that if it may be used continuously until the completion of the facilities, these need to be filled up and not used anymore.
Simple hole fitted with a slab	About 20%	Necessary to check by eyes if it meets the standards. [Issues to be considered] If people keep on using it, raise people's awareness on that fact that it is the lowest health and promote plans for constructing new improved latrines (VIP latrines).

[5] In Senegal masons, refer to standalone sanitation facilities construction technicians.
[6] Local Water Supply and Sanitation Plan: PLHA, established within the RC with the support of the World Bank. (See section 2.2.2 of Chapter 2)
[7] In the household survey results (qualitative survey), 100% of the household expressed their willingness to pay for the cost. On the other hand, if the number of households that agreed to give cash contribution still remains low, most household responded that they could afford about 10% of the costs by providing their labor force or locally available materials.

VIP and DLV	Very few	Give directions on a methodology for an appropriate use, management and maintenance.

Remark: as for the proportion of households, the baseline survey results conducted in 2009 for the selection of the priority sites and the results of the baseline qualitative survey were added.

8.3.3 Project implementation units

According to the survey results, the smallest target unit for the implementation of the master plan will be a village.

Study was conducted to try establishing master plan with the wide scale as based on the village groupe like water supply master plan. However in target region, while considering that differences could not be observed in the mutual relations between the administrative units such as the regions, the departments and the districts, etc.; and the population size among others. It was difficult to specify the parameters enabling making up some large-scale groups. Consequently, the smallest unit in this present master plan will be a village.

8.3.4 Reviewing the Sanitation Master Plan

The sanitation systems include the following three constituents, namely 1) the construction of sanitary facilities, 2) an appropriate application of hygiene notions and health and sanitation related knowledge; and 3) a sustainable implementation system within the villages. It is made of the below six components:

- Component 1 : Construction of household and public sanitation facilities
- Component 2 : Activities to identify local resources (human, budget, existing approach, natural resource…)
- Component 3 : Activities to improve capabilities of human resources
    - Development (training) of rural sanitation education staff (mainly women)
    - Development (training) of technician and staff of ASUFOR or CBO related to amelioration of sanitation condition in villages
- Component 4 : Implementation of activities to improve sanitation concept within village
- Component 5 : Establishment of a sustainable implementation system (including supervision and evaluation)
- Component 6 : Other activities (to prevent open-air defecation)

The study on the content was conducted in line with the results of the study on the sanitation system's components, on the PEPAM monitoring indicator[8] and on the relaxing of the PEPAM specifications already mention in section 2.2.5 in Chapter 2 of Main Report.

(1) Scope of the plan
The scope of the Master Plan will be same as that of the rural sanitation sytstem (onsite saniataion) .

(2) Selecting the target regions for the introduction of the sanitation facilities
For the installation of the sanitation facilities, priority is given to the regions where daily water supply is possible. It is aimed to ensure that an improved sanitary environment will be established in the villages through the sanitation facilities development project and by achieving synergy with the water supply facilities development program. But the water utilized to improve sanitation condition and behaviour change on hygiene and sanitation, it is not necessary to controle water quality as same way as drinking water, also it is essential that the villagers that are forced to use the water from shallow well (puits) or river, need to get knowledge and do appropreate practice concening health and hygiene. So, the selection of the target site shall be taken into consideration for the villages where usually get

[8] Supporting the establishment of system for the monitoring of the Millennium Drinking water supply and sanitation program, Report No2 ; Definition of the final version of the PEPAM monitoring indicators, September 2006,