Northern Tunisia Water Resource Management Project

Report of a preappraisal mission for the World Bank
april 26 - may 4, 1992

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Table of contents

1. Introduction

The World Bank, Middle East and North Africa Country Department I, requested the Agricultural University, Department of Hydrology, Soil Physics and Hydrology, to make the author of this report available for the preappraisal mission of the Northern Tunisia Water Resource Management Project.
The author's assignment in the preparation of the project has been to propose appropriate measurement systems and to assess their approximate costs in the existing and planned water transfer facilities on behalf of the end users: irrigation and water supply (letter dated August 8, 1991).
The mission took place from April 26 through May 4, 1992.

During the mission discussions have been held at the following institutes:

- Direction Générale de Grands Travaux Hydrauliques, Ministère de l'Agriculture, directeur Mr. Khazen.
- Société d'Exploitation du Canal et des Adductions des Eaux du Nord (SECADENORD), directeur Mr. Ben Azouz, Chef de Service Mr. Ghorbal and ingénieur Mr. Ben Cheikh.

On April 28 an extensive field visit was made along the Medjerdah Cap-Bon Canal with Mr. Ghorbal and also attended by Mr. Cottereau of the Compagnie National du Rhône, France.
A complete itinerary of the mission is given in Annex 1.

This report is composed of the following sections:

1. Introduction
2. Water resource management
3. Medjerdah Cap-Bon Canal
4. Field visit and discussions with SECADENORD
5. Conclusions, recommendations and cost-assessment.

2. <u>Water resource management</u> (fig. 1 and 2)

The Tunisian Government outlined since the early seventies a strategy for optimal development of its limited water resources. The present project would assist the Government to manage its scarce water resources to meet present and future water demand up to 2010.
Since 1975 the Ministry of Agriculture is responsible for the development of all water resources. Studies and development of water resources for all users are committed to the Directorate General for Studies and Main Hydraulic Works (DGEGTH) within the State Secretariat for Hydraulics of the Ministry of Agriculture.
Operation and maintenance of main transfers between surface water resources and users is the responsibility of the Company for the Exploitation for the Medjerdah Cap-Bon Canal and Northern Conveyors (SECADENORD). This company sells water to both users, namely:

- The National Water Supply and Distribution Company (SONEDE) for drinking water
- The Regional Commissariats for Agricultural Development (CRDA) for irrigation water.

The Government's strategy for optimal development of water resources covers practically the whole northern part of the country, including all the main river basins (figures 1 and 2). Among these the Medjerdah river and its tributaries form the backbone of the water resource mobilization efforts. In 1984 the Sidi Salem Dam has been constructed in the Medjerdah river. Downstream of this dam the El Aroussia Weir has been constructed in the Medjerdah River. From this barrage starts the Medjerdah Cap-Bon Canal, which has a total length of 120 km. Water is withdrawn from the MCB Canal, both for water supply and irrigation.

Management of water resources is done by DGEGTH by the use of a computer model EAU TUN 3, which simulates river flows, reservoir operation taking into account inflows, evaporation, storage, diversions, withdrawals and capacities of interconnecting conveyance systems (pipes, canals and pumping stations). Among the main issues constraining an optimal water resource development, belong the techniques to monitor waterflows from water resource to water users.

Les Barrages alimentant le Canal dans le cadre du plan directeur des eaux du Nord

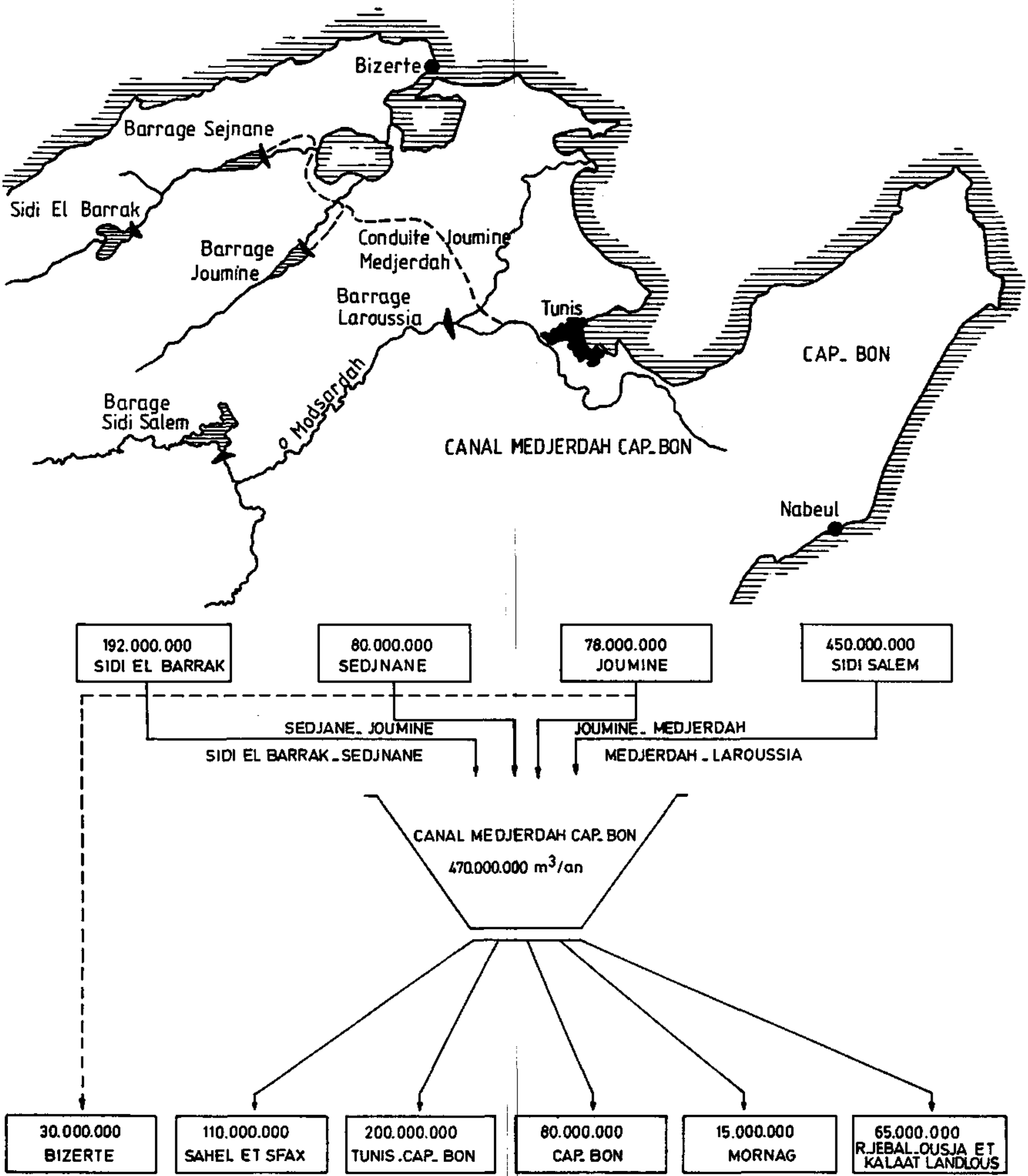


Fig. 1. The main reservoirs in Northern Tunesia.

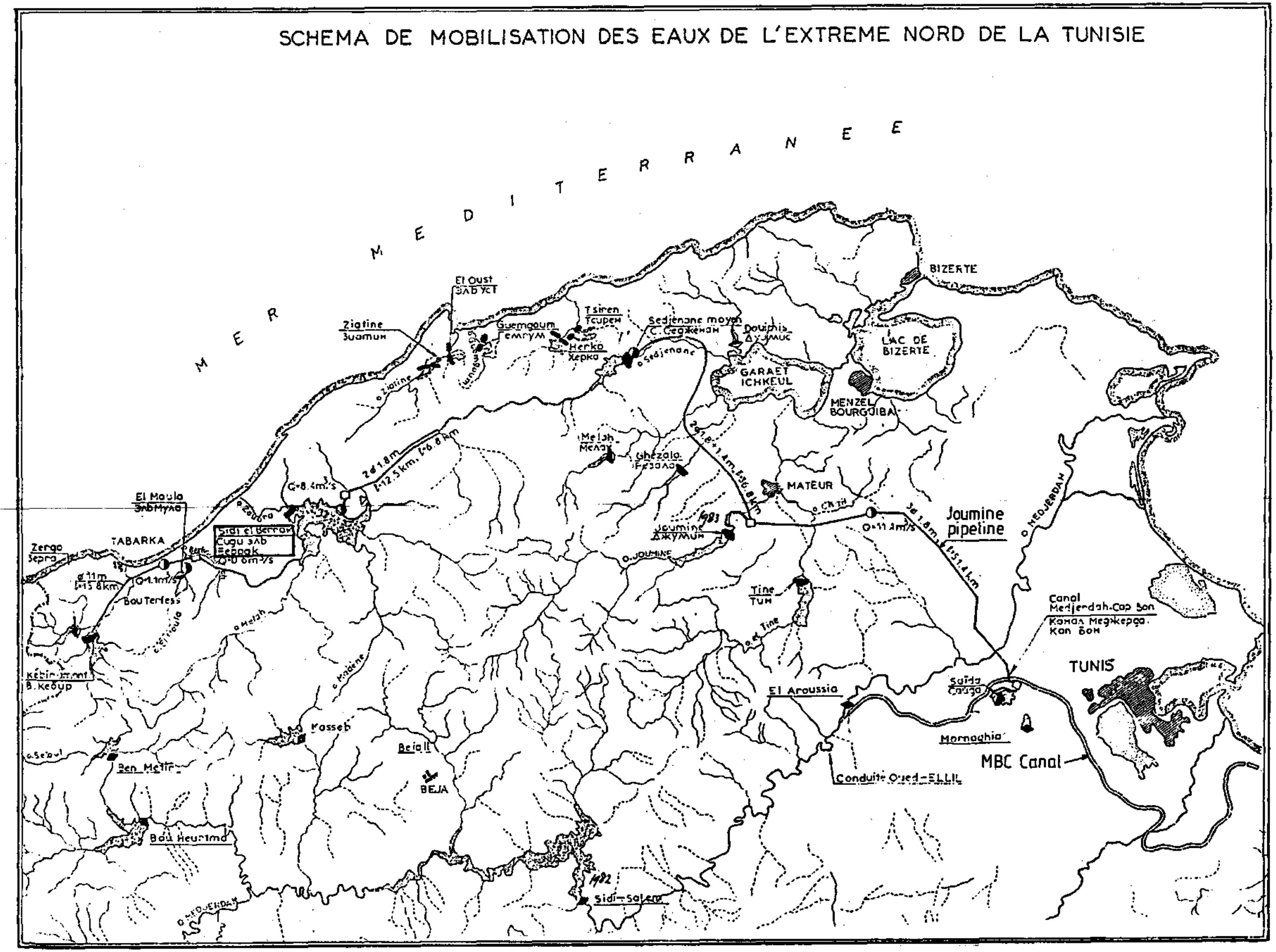


Fig. 2. Water transfer scheme in Northern Tunesia

One of the Project Objectives is therefore, to optimize development, monitoring and operation of Tunisia's water transfer and distribution facilities. This can be achieved by implementation of the following main components:

- construction of the Sidi El Barrak Dam in the Zouara River
- staff training for operation and management of water production and distribution systems
- technical assistance and studies to develop flow monitoring systems
- rehabilitation, replacement and installation of measuring equipment.

The present system for monitoring of the main conveyance structures can be improved (be made more reliable).

To get some insight into the weak points of the flow monitoring system, the water balance of the MCB Canal has been studied during the present mission. This reconnaissance study is focussed on the methods and instruments to measure discharges in the MCB system (inflow and outflow), the density of the network and the data transport and storage.

3. Medjerdah Cap-Bon Canal

3.1 Description of the Canal (fig. 3 and table I)

The Medjerdah Cap-Bon Canal starts just upstream of the El Aroussia Weir in the Medjerdah River. The MCB Canal conveys water to Tunis (drinking water) and to various irrigation schemes.
The Medjerdah Cap-Bon Canal with a total length of 120km was carried out in the period 1980-1984. The canal starts at the right bank of the river at El Aroussia with a capacity of Q = 16 m^3/s. The major part of the canal is an open concrete lined canal with a trapezoidal cross-section.

The main characteristics of the canal are as follows:

- total length about 120 km
- design discharge at El Aroussia Q = 16 m^3/s
- bottom slope S = 12 . 10^{-5}
- twenty automatic regulating structures divide the canal into twenty sections, each of them about 6 km long
- canal cross-section between the intake and the Bejaoua pumping station:
  bottom width b = 2.80 m
  design depth d = 2,60 m
  trapezoidal profile with side slopes m = 1.5 (1 vertical, 1.5 horizontal)
  concrete lined with a Manning factor k_M = 66 $m^{1/3}/s$
- head difference over the regulators Δh = 0,20 m for design discharge (in most cases).

Figure 3 shows the longitudinal section of the canal.
Table I gives all the relevant information on water levels (both for Q = Q_{design} and Q = 0) and bottom levels along the canal.
As can be seen from figure 3 and table I, water is pumped up two times as follows:

- pumping station Bejaoua at km 27.7 with 6 pumps and a capacity of Q = 2 m^3/s each at a head of Δh = 16 m
- pumping station Foundouk Jédid at km 106.0 with 4 pumps and a capacity of Q = 2 m^3/s each at a head of Δh = 32 m.

Just downstream of the first pumping plant the pipeline from the Joumine reservoir discharges into the canal (capacity 4 m^3/s).

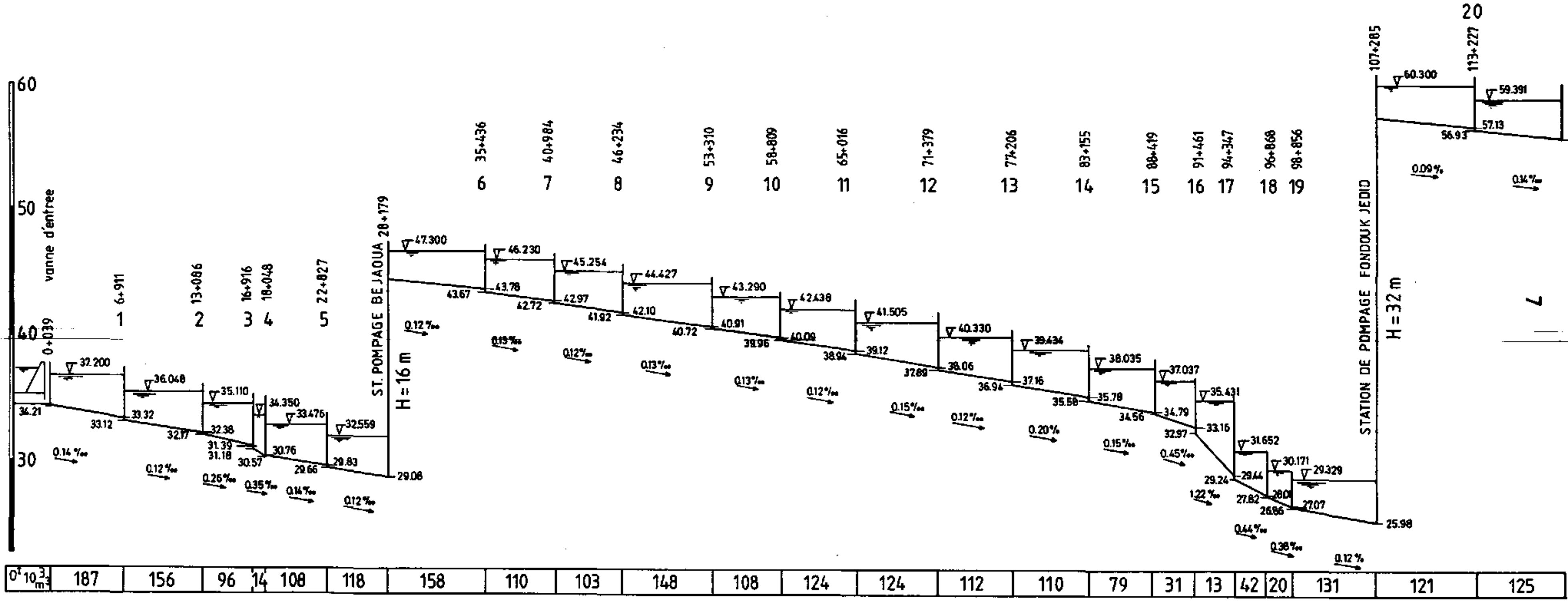


Fig. 3. Longituninal section of the MCB Canal.

NIVEAUX D'EAU AUPRES DES SECTIONS DEFINITIVES DE REGULATION

Sections de régulation	*P.K.	Distance (m)	Section prévue: Débit (m^3/s)	Section prévue: Largeur du fond (m)	Section prévue: Profondeur d'eau (m)	Section prévue: Vitesse (m/s)	Section prévue: Pente longitudinale	Niveau d'eau (m)	Perte de charge (m)	Cote du fond (m)	Niveau d'eau statique (m)
Départ	0 + 000							37,200		34,840	37,700
		39,80	16,00		2,36						
Vanne d'entrée	0 + 039,8							37,200 / 36,900	0,300	34,840 / 33,310	37,200
		25,20	"						0,100		
Conduite enterrée	0 + 065 / 0 + 300	235,00	"	2,50	2,59	1,240	1/3 000	36,800 / 36,740	0,060	34,200 / 34,137	37,200
		6599,00	"						0,792		
Régulateur N° 1	6 + 899 / 6 + 923	24,00	-	2,80	2,60	0,928	1,2/10 000	35,948 / 35,748	0,200	33,348 / 33,148	37,200 / 36,048
		6151,00	"	"	"	"	"		0,737		
Régulateur N° 2	13 + 074 / 13 + 098	24,00						35,011 / 34,811	0,200	32,410 / 32,210	36,048 / 35,110
		10,00	"						0,001		
Aqueduc N° 1	13 + 108 / 14 + 471	1363,00	"	5,30	"	1,463	1/3 000	34,810 / 34,307	0,530	32,130 / 31,687	35,110 / 35,110
		2433,00	"	2,80	"	0,928	1,2/12 000		0,293		
Régulateur N° 3	16 + 904 / 16 + 928	24,00						34,015 / 33,815	0,200	31,414 / 31,214	35,110 / 34,355
		10,00							0,001		
Aqueduc N° 2	16 + 938 / 18 + 034	1096,00	"	5,30	"	1,463	1/3 000	33,814 / 33,377	0,437	31,134 / 30,777	34,355 / 34,355
		2,00									
Régulateur N° 4	18 + 036 / 18 + 060	24,00						33,377 / 33,177	0,200	30,776 / 30,576	34,355 / 33,476
		4755,00	"	2,80	"	0,928	1,2/10 000		0,689		
Régulateur N° 5	22 + 815 / 22 + 839	24,00						32,488 / 32,288	0,200	29,859 / 29,659	33,476 / 32,559
		4867,00	"	"	"	"	"		0,612		
Station P.Béjaoua	27 + 706,19 / 28 + 179,62	473,43	11,00	3x ø1,4				31,676 / 47,000		29,076 / 44,400	32,559 / 47,300
		7242,80	16,00	2,80	"	"	"		0,870		
Régulateur N° 6	35 + 422,5 / 35 + 449,5	27,00						46,130 / 45,930	0,200	43,870 / 43,670	47,300 / 46,230
		4061,00	11,20	2,50	"	0,848	"		0,488		
Aqueduc N° 3	39 + 511 / 39 + 681	170,00	"	4,00	2,24	1,550	1/2 000	45,442 / 45,307	0,135	43,182 / 43,047	46,230 / 46,230
		1291,00	"	2,50	2,26	0,848	1,2/10 000		0,155		
Régulateur N° 7	40 + 972 / 40 + 996	24,00						45,152 / 44,952	0,200	42,694 / 42,694	46,230 / 45,254
		5226,00	"	"	"	"	"		0,626		
Régulateur N° 8	46 + 222 / 46 + 246	24,00						44,326 / 44,126	0,200	42,067 / 41,867	45,254 / 44,427
		229,00	"	"	"	"	"		0,029		
Aqueduc N° 4	46 + 475 / 46 + 592	117,00	"	4,00	2,24	1,550	1/2 000	44,097 / 43,992	0,105	41,839 / 41,734	44,427 / 44,427
		6706,00	"	2,50	2,26	0,848	1,2/10 000		0,805		
Régulateur N° 9	53 + 298 / 53 + 322	24,00						43,187 / 42,987	0,200	40,930 / 40,730	44,427 / 43,290
		5475,00	"	"	"	"	"		0,657		
Régulateur N° 10	58 + 797 / 58 + 821	24,00						42,330 / 42,138	0,192	40,078 / 39,878	43,290 / 42,438
		6182,00	"	"	"	"	"		0,7419		
Régulateur N° 11	65 + 004 / 65 + 028	24,00	10,38					41,396 / 41,206	0,190	39,146 / 39,026	42,438 / 41,506
		2575,00	"	"	2,18	0,832	"		0,309		
Aqueduc N° 5	67 + 603 / 67 + 803	200,00	"	4,00	2,13	1,530	1/2 000	40,897 / 40,737	0,160	38,715 / 38,570	41,506 / 41,506
		1098,70	"	2,50	2,18	0,832	1,2/10 000		0,135		
Passage sous voie ferrée	68 + 901,7 / 68 + 933,7	32,00						40,604 / 40,504	0,100	38,442 / 38,340	41,506 / 41,506
		2433,00	"	"	"	"	"		0,291		
Régulateur N° 12	71 + 367 / 71 + 391	24,00						40,213 / 40,030	0,200	38,050 / 37,850	41,506 / 40,330
		5803,00	"	"	"	"	"		0,696		
Régulateur N° 13	77 + 194 / 77 + 218	24,00						39,334 / 39,134	0,200	37,154 / 36,974	40,330 / 39,434
		398,00	9,765	2,30	2,16	0,819	1,2/10 000		0,048		
Petit siphon	77 + 616 / 77 + 636	20,00	"	3,0x3,0		1,560		39,086 / 39,066	0,089	36,926 / 36,830	39,434 / 39,434
		2081,60	"	2,30	"	0,819	"		0,250		
Siphon Oued Hamma	79 + 717,6 / 79 + 823,6	106,00	"	2,5x2,5				38,840 / 36,340	0,500	36,674 / 36,174	39,434 / 39,434
		3329,00	"	2,30	"	"	"		0,400		
Régulateur N° 14	83 + 153 / 83 + 177	24,00						37,940 / 37,735	0,205	35,775 / 35,575	39,434 / 38,035
		5228,60	"	"	"	"	"		0,785		
Régulateur N°15	88 + 405,6 / 88 + 432,6	27,00						36,935 / 36,735	0,200	34,776 / 34,536	38,035 / 37,036
		160,00	8,830	3,30	2,20	1,130	1/2 500		0,234		
Tunnel Hammam-Lif	88 + 592,6 / 91 + 438,6	2846,00	"	"	"	"	"	36,501 / 35,362	1,139	34,302 / 33,163	37,036 / 37,036
		11,00	"	"	"	"			0,003		
Régulateur N°16	91 + 449,6 / 91 + 473,6	24,00						35,359 / 35,131	0,228	33,159 / 32,967	37,036 / 35,431
		39,14	"	"	2,15	1,380	1/2 000		0,0194		
Aqueduc N°6	91 + 512,74 / 91 + 587,74	75,00	"	4,00	"	1,460		35,112 / 35,082	0,030	32,967 / 33,016	35,431 / 35,431
		322,30	"	2,30	2,07	0,800	1,2/10 000		0,0388		
Aqueduc N°7	91 + 910,0 / 92 + 045,0	135,00	"	4,00	2,15	1,460	1/2 000	35,043 / 34,903	0,140	32,977 / 32,732	35,431 / 35,431
		89,00							0,045		
Aqueduc N°8	92 + 134,0 / 92 + 204,0	70,00	"	"	"	"	"	34,858 / 34,808	0,050	32,667 / 32,610	35,431 / "
		204,00	"	3,00	"	1,380	"		0,101		
Conduite forcée	92 + 408,0 / 94 + 332,0	1924,00	"	ø2,40		1,950		34,707 / 31,552	3,155	32,506 / 29,306	" / "
Régulateur N°17	94 + 332,0 / 94 + 362,0	30,00	"					31,552 / 31,352	0,200	29,402 / 29,202	35,431 / 31,652
		65,90	"	3,00	"	1,380	"		0,033		
Aqueduc N°9	94 + 427,9 / 94 + 512,9	85,00	"	4,00	"	1,460	"	31,319 / 31,284	0,035	29,169 / 29,212	" / "
		1877,00	"	2,30	2,07	0,800	1,2/10 000		0,317		
Siphon Bord Cédria	96 + 390,0 / 96 + 748,0	358,00	"	2,3x2,3		1,670		30,967 / 30,084	0,883	28,895 / 28,012	" / "
		108,00	"	2,30	"	0,800	"		0,013		
Régulateur N°18	96 + 856,0 / 96 + 880,0	24,00	"					30,071 / 29,871	0,200	28,001 / 27,801	" / 30,171
		1384,00	"	"	"	"	"		0,390		
Tunnel Moktar	98 + 264,0 / 98 + 804,0	540,00	"	3,30	2,20	1,330	1/2 500	29,481 / 29,264	0,217	27,281 / 27,065	"
		40,00	"	"	"	"	"		0,020		
Régulateur N°19	98 + 844,0 / 98 + 868,0	24,00	"					29,244 / 29,029	0,215	27,049 / 26,887	30,171 / 29,329
		96,72	"	3,00	2,15	1,380	1/2 000		0,048		
Aqueduc N°11	98 + 964,72 / 99 + 229,72	265,00	"	4,00	"	1,460	"	28,981 / 28,836	0,145	26,839 / 26,792	"
		6793,00	"	2,30	2,07	0,800	1,2/12 000		0,815		
Station P. Fondouk D.	106 + 023,0 / 107 + 285,7	1262,70		2xø1,25				28,021 / 60,000		25,977 / 57,930	" / 60,300
		2998,00	"	2,30	"	"	1,2/10 000		0,360		
Aqueduc N°12	110 + 284,0 / 110 + 394,0	110,00	"	4,00		1,460	1/2 000	59,640 / 59,540	0,100	57,570 / 57,470	60,300
		2821,00	"	2,30	"	0,800	1,2/10 000		0,320		
Régulateur N°20	113 + 215,0 / 113 + 239,0	24,00	"					59,200 / 59,000	0,200	57,130 / 56,930	60,300 / 59,300
		5527,00	"	"	"	"	"		0,660		
Aqueduc N°13	118 + 766,0 / 118 + 811,0	45,00	"	4,00		1,460	1,2/2 000	58,340 / 58,270	0,070	56,270 / 56,200	" / "
		1354,78	8,830	2,30	2,07	0,800			0,130		
Extrémité du canal	120 + 165,76							56,140		56,200	59,300

Table I Waterlevels and bottomlevels along the MCB Canal

3.2 Description of the AVIO regulating structure (fig. 4 and 5)

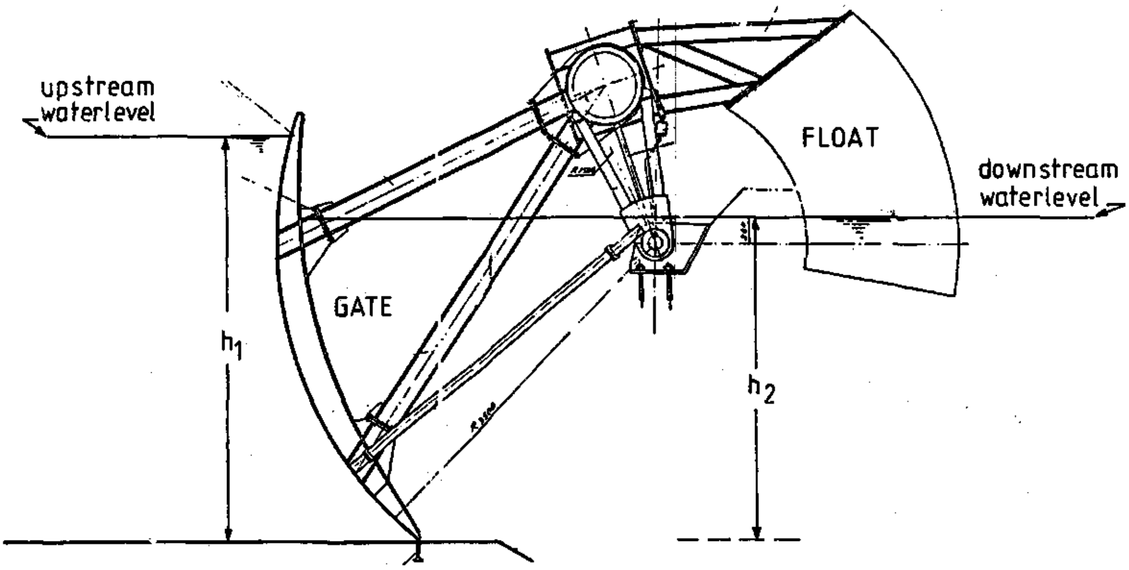
The MCB canal has been divided into 20 pools or sections with an average length of about 6 km each. The sections are separated by automatic regulators (vannes de régulation).
Two different types of regulators can be distinguished:
- AVIS regulators are overflow structures
- AVIO regulators are undershot gates (orifices).

In the MCB canal only AVIO regulators have been applied. The regulators in the MCB canal are operated in concrete made trapezoidal sections (6:1) as can be seen from figure 4.
The regulator consists of a curved gate (more or less the shape of a radial- or taintergate) and a float.
The function of the automatic AVIO regulator is to maintain a certain desired downstream waterlevel.
Downstream control is a user oriented system, where the water is supplied on demand. An increase in demand within a pool will cause a drop in waterlevel, accordingly resulting in a drop of the float. This causes the gate to open and to supply more water which will bring the waterlevel back to its target level. This will occur in all the pools upstream up to the intake. In other words, signals concerning the demand are passed on in an upstream direction.

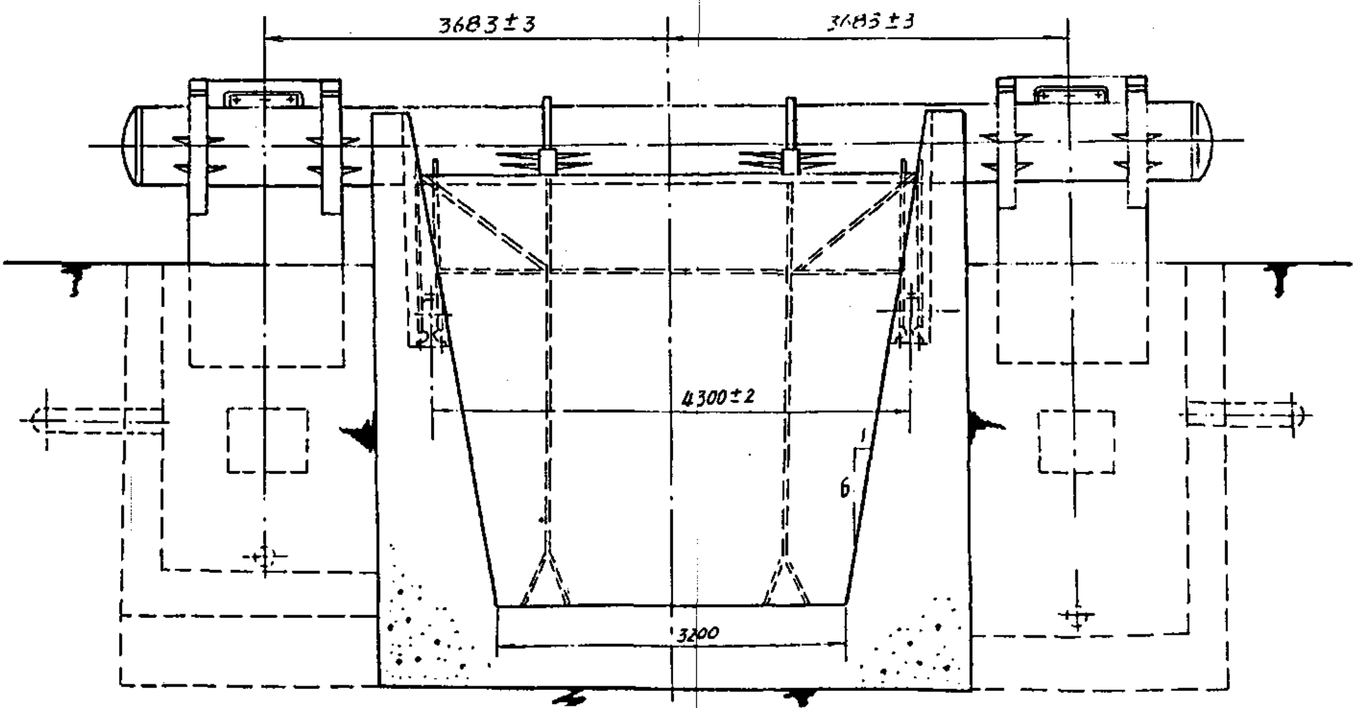
The European manufacturer of the automatic regulators AVIS and AVIO is Alsthom Fluids (Neyrtec). The regulators are subjected to the following limitations so as to fulfil a well performing control system with a minimum instability in water discharge and waterlevels:
- a minimum pool length
- a minimum decrement.

Instability is defined as not damped oscillations, which will be reduced by placing the float(s) in a stilling well.
The decrement is defined as the difference in waterlevel just downstream of the gate between zero-flow (the so called static waterlevel) and design flow. The decrement can be adjusted. Alsthom Fluids gives the following minimum value:

$d > 2 * v^2/2g$ where v is the mean flow velocity (m/s).



cross section AV10 regulating structure



cross section canal in the AV10-section.

Fig. 4. The AV10 regulating structure.

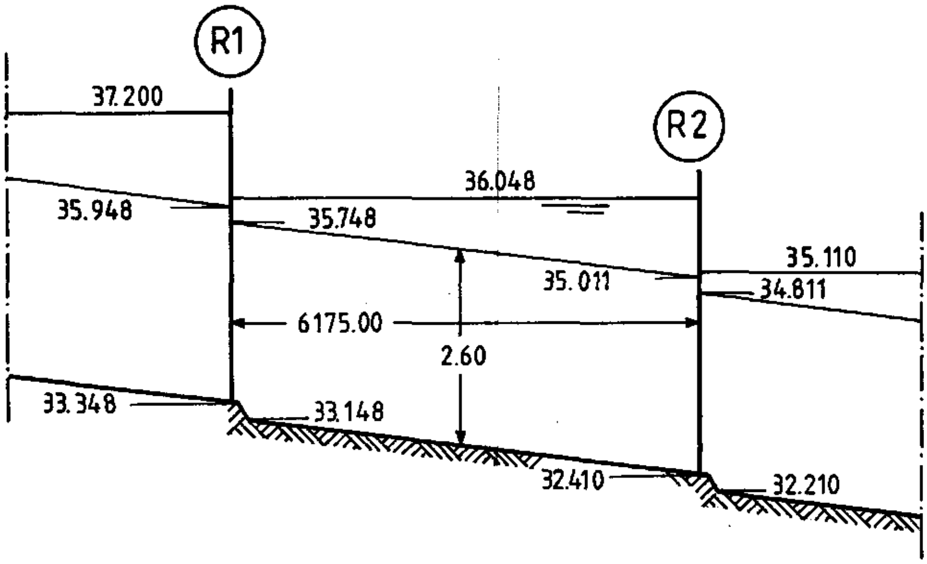


Fig. 5. Design waterlevels in the pool between R1 and R2.

Figure 5 is an illustration of the design criteria for the pool which is situated between the regulators R1 and R2:

- the decrement for both gates is d = 0.30 m
- the pool length is l = 6175 m
- the storage wedge volume is V = 59 . 10^3 m^3.

The overall stability of the system depends on the following factors:

- the decrement.
  The larger the decrement, the more stable the regulator will operate: the regulator becomes less sensitive to minor disturbances.
- the withdrawal ΔQ.
  The larger the withdrawal, the greater the oscillations. A gradual increase or decrease of ΔQ will reduce the instability.
- the gate width.
  The larger the width, the more stable the reaction of the gate. The gates in the MCB canal are operated in trapezoidal sections (1:6) as can be seen in figure 4 which probably is also favourable for the stability.
- the storage wedge volume V.
  The larger this volume, the better the performance.
- the canal roughness k_M.
  A rough canal will dampen oscillations. The MCB canal is rather smooth with k_M = 66 $m^{1/3}/s$ (design value).

The discharge through the AVIO regulators can be estimated applying the following equation:

$$Q = C_e \cdot A \cdot \sqrt{2g(h_1 - h_2)}$$

where

Q	discharge (m^3/s)
C_e	contraction coefficient (-)
A	area of the opening underneath and along the sides (m^2)
h_1	upstream waterdepth related to the sea level (m)
h_2	downstream waterdepth related to the sea level (m)
g	gravitational acceleration $g = 9.81\ m/s^2$.

The contraction coefficient C_e can be defined by calibration in an hydraulic model.
The cross sectional area A is a function of the gate opening a.

During the mission a number of regulators have been visited, which can be classified as follows:

a) gates, installed against the backside of a conduit
   - the intake structure at El Aroussia
   - the structure at the end of the Joumine pipeline

b) gates, operating in the MCB canal in a trapezoidal section (6:1)
   - regulator 2 at km 13.1 just upstream of an aquaduct
   - regulator 6 at km 35.4 downstream of the SONEDE offtake
   - regulator 12 at km 71.4 downstream of an irrigation offtake.

All the other regulators are of the same type, according to information from SECADENORD.

3.3 Water inflow and withdrawals MCB canal

The canal receives water at two places:

- El Aroussia intake with a design capacity $Q = 16\ m^3/s$ taken from the Medjerdah River. Salinity about 2 grammes/liter.
- Joumine pipeline downstream of the Bejaoua pumping station at km 28. The design capacity of the pipeline is $Q = 4\ m^3/s$ taken from the Joumine Reservoir. Salinity 0.5 gramme/liter.

Withdrawals from the canal take place at twelve places:

distance from El Aroussia intake (km)	way of withdrawal	demand category	withdrawal capacity (m^3/s)
35.204	pumps	Tunis water supply	5.00
68.750	pumps	Khelidia irrigation	0.67
71.471	pumps		0.30
77.273	pumps	Mornag irrigation	1.02
80.632	pumps		0.76
80.759	pumps		0.67
104.334	pumps	Soliman irrigation	1.25
108.155	gravity	Cap Bon irrigation	2.84
111.363	gravity		0.64
117.382	gravity		0.52
120.116	pumps		1.09
120.156	pumps	Sousse-Sfax irrigation	2.00

4. Field visit and discussions with SECADENORD

4.1 General

On April 28 a field visit along the MCB canal took place, followed by discussions on April 29, both with representatives of SECADENORD. Much attention has been paid to the aspect of measurements, particularly flow measurement and its reliability.

It is more or less surprising that the transported volumes of water are measured by SECADENORD, while the withdrawals through the offtakes are estimated by the end users SONEDE (drinking water) and CRDA (irrigation water).

In the following sections the most important impressions of the discussions are reported.

4.2 El Aroussia

The El Aroussia complex consists of the following structures:

- the barrage composed of three curved and movable overflow structures in the Medjerdah River. They control the upstream waterlevel and discharge the surplus water
- a hydropower station along the left bank
- the old intake structure at the right bank to withdraw water to the old canal, length about 60 km, for gravity irrigation during daytime. Design discharge Q = 8 m^3/s. The structure is a steel automatic type (AVIO) and has two gates
- the new intake structure at the right bank to withdraw water to the MCB canal, length about 120 km. Design discharge Q = 16 m^3/s. The structure has been designed and constructed by a Tunisian-Chinese consortium, and is of the same type as the old intake structure. There are two AVIO gates.

  Just upstream of this regulator, vertical gates (batardeau) have been constructed, which are open over a height of a = 1.00 m (in future a = 2.00 m).

  Discharges are not measured here, nor the gate opening. Waterlevels are read hourly, by reading staff gauges upstream and downstream of the gate. SECADENORD estimates the intake discharge at the Bejaoua pumping station (km 27), as there are no withdrawals between El Aroussia and Bejaoua.

Besides the waterlevels of the MCB intake structure, the turbidity and salinity are measured by taking samples which are locally analysed:

- turbidity is measured with a minimum frequency of once per day with a Hach model 2100A turbidity meter. If the turbidity is more than 1000 ntu (nephelometrique turbidity units), then samples are taken hourly. And if it is more than 3000 ntu, then the gates will be closed.
- salinity is derived from the measured conductivity and temperature with the conductometer LF 191 WTW, once per hour. Each two hours the salinity values are transmitted to the SECADENORD head-office, by radio.
  Salinities are also measured at km 35 downstream of the junction with the Joumine pipeline and at km 106, Foundouk Jédid pumping station.

All the measured values (waterlevels, turbidity and salinity) are reported by SECADENORD in books (not yet in a database system).

During the visit the measured waterlevels upstream of the intake were about +37.90 m (which was 0.20 m more than the maximum design level +37.70 m).

It is recommended to store all the measured values of waterlevels, discharges, turbidity and salinity in a database system.

4.3 The MCB canal, characteristics and sedimentation

The characteristics of the MCB canal in the most upstream section are as follows:

- bottom width b = 2.80 m
- design depth d = 2.60 m
- trapezoidal cross section with side slopes m = 1.5
- concrete lined
- average bottom slope $S = 12 \cdot 10^{-5}$
- design discharge $Q = 16\ m^3/s$.

From these data the following characteristics are derived:

- mean flow velocity v = 0.92 m/s
- Mannings roughness coefficient $k_M = 66\ m^{1/3}/s$.

For discharges in this section $Q < Q_{design}$ the waterlevels will be higher and consequently the flow velocities will be much lower.

From table I can be seen that the flow velocities in the aquaduct sections are about v = 1.50 m/s at design discharge, so as to prevent sedimentation in these sections, which are inaccessible for a dragline.

Sedimentation in the MCB Canal is one of the main problems for SECADENORD. Along the 120 km MCB canal three draglines are cleaning the canal from sediments (fine silt and clay). This material comes from the Medjerdah River. Probably the intake is not located at the best place.

Dredging starts already in front of the intake structure along the river's right bank.

Sedimentation in the MCB canal is a serious problem for the following reasons:

- reduction of the canal capacity
- the costs are about TND 400.000 per year
- no sufficient place to store the dredged material on the banks.

The reduction of the canal capacity can be expressed as follows: clay layers of 0.40 m/0.60 m/0.80 m will lead to waterlevel rises of 0.14 m / 0.23 m/0,32 m respectively for the design discharge $Q = 16\ m^3/s$.

It is recommended to reduce sedimentation in the MCB canal by one of the following actions:

- reshaping the intake conditions, or
- a silt trap in the most upstream part of the canal.

The best solution depends mainly on the diameter of the sediments.

It will be recommended to carry out an engineering study on the sedimentation problem (see chapter 5).

4.4 Pumping station Bejaoua

Water is lifted over a height $\Delta h = 16$ m by six pumps with horizontal axles. Theoretically the capacity is $Q = 2.0\ m^3/s$ per pump.

In order to verify the pump capacity (including pipelines), discharge measurements have been carried out in 1986 and 1991 by the Direction de

Ressources en Eau, DGRE (Ministère de l'Agriculture). The measurements were carried out with a propellor. In 1986 the results were satisfactory (close to Q = 2 m^3/s per pump). In 1991 the measurements showed an average discharge of Q = 1.8 m^3/s instead of Q = 2.0 m^3/s.

In 1991 the calibration was carried out on July 26 and 27. Velocities have been measured in five sections (verticals) and in four points per vertical. The mean velocity in the canal - one pump in operation - is about v = 0.11 m/s, which is rather low (high inaccuracy). The test results were as follows:

pump(s)	discharge (m^3/s)	Q_{meas}/Q_{pump}	
1	1.663	0.83	
2	2.057	1.03	
3	1.792	0.90	0.91 (average)
4	1.854	0.93	
5	1.727	0.86	
6	1.932	0.97	
1+2	3.511	0.88	
3+4	3.672	0.92	0.90 (average)
5+6	3.634	0.91	

The overall error in these measurements is about 10%.
Possible sources of errors are:

- non permanent flow conditions during the calibration period (variation in waterlevels or power)
- instrumental errors in the measured low flow velocities
- errors due to the number of measured point velocities and due to the method of calculation of the total discharge.

Recommendations:

- The calibration of the pumping section shall be carried out two times per year under strictly permanent flow conditions, and with a modern currentmeter (for field use).
- In order to reduce the instrumental error in measuring low flow velocities, it is advisable to calibrate combinations of two or three pumps.
- Select sufficient velocities over the cross section of the canal and apply the mid section or the mean section method as recommended by ISO-standards.

4.5 Inflow of the Joumine-pipeline

At a short distance downstream of the Bejaoua pumping station, the Joumine pipeline is connected to the canal system. The discharges from the pipeline are regulated with an AVIO-gate more or less similar to the AVIO gates of the intake. Then the discharges pass a module à masque structure before they join the MCB canal.

The module à masque structure (Neyrpic module) was designed to allow the passage of an almost constant flow from a basin in which the variation of the waterlevel is restricted. Flow through the structure is simply regulated by opening or closing the sliding gates. The installed structures have one single baffle (type XI) and have a unit discharge of 1.00 $m^3/s/m'$ (according to the design drawing of Viziterv, 1982).
The total number of openings is 12, where the widths are as follows:

width (m)	number of gates
0.1	4
0.2	2
0.4	2
0.6	4

The total width is B = 4.00 m, resulting in a capacity of Q = 4 m^3/s

Any discharge in the range 0.1 m^3/s < Q < 4.0 m^3/s can be installed with steps ΔQ = 0.1 m^3/s.
To keep the module functioning properly, frequent maintenance is required. Provided the upstream head - the level in the basin between AVIO regulator and the module - is maintained between the limits of application, the error in discharge measurement will be 5 to 10%.

To improve the reliability of discharge measurements from the Joumine pipeline the installation of an acoustic flowmeter at the end of the pipe may be considered. (Water withdrawn from the Joumine reservoir is measured with an ultrasonic BEN flowmeter).

4.6 Pumping station Foundouk Jédid

Water is lifted over a height Δh = 32 m by four pumps with vertical axles. Theoretically the capacity is Q = 2.0 m^3/s.

In order to verify the capacities of the pumps (including pipelines), discharge measurements have been carried out in 1986 and 1991. In 1986 the results were satisfactory, in 1991 the measurements showed an average discharge of Q = 2.2 m^3/s instead of Q = 2.0 m^3/s, which seems unlikely. The test results of the recalibration in 1991 were as follows:

pump(s)	discharge (m^3/s)	Q_{meas}/Q_{pump}	
1	2.413	1.21	
2	2.304	1.15	
3	2.261	1.13	1.17 (average)
4	2.382	1.19	
1+2	4.421	1.11	
3+4	4.127	1.03	1.07 (average)

The overall error in these measurements is at least 10%.
Possible errors are expected to be the same as for the recalibration of the Bejaoua pumping station.

The same recommendations as given for the Bejaoua pumping station are also valid for the Foundouk Jédid pumping station.

Technical assistance for about two weeks is recommended in order to recalibrate both pumping stations along modern standards for flow measurement.

4.7 Offtakes (fig. 6)

Water is withdrawn at 12 locations along the MCB canal, as indicated in section 3.3. The quantities are calculated as follows:

- pumping hours are counted in the nine offtakes where water is pumped up from the canal. Using the manufacturer's pump-curve, the withdrawn water volumes are estimated by SONEDE (for water supply) and by CRDA (for irrigation water).
  The overall error in this method of discharge calculation is expected to be not better than about 10%.
- in the areas served by the three gravity offtakes for the Cap Bon irrigation, a large number of house-watermeters have been installed in the irrigated fields. CRDA calculates the total withdrawn volumes.

The overall error in this method of discharge calculation is expected to be not better than about 10%.

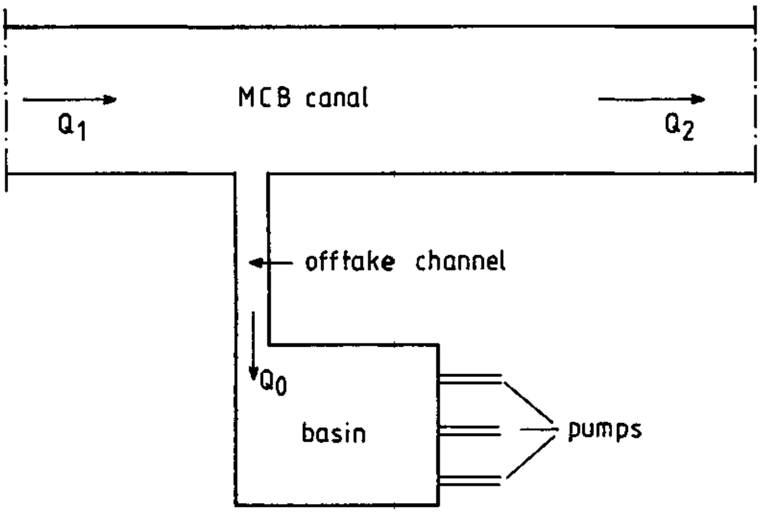


Fig. 6. Typical layout of an offtake

The withdrawn quantities are reported monthly for most offtakes.
Daily reports are given for the following offtakes:

km 35.204 SONEDE
km 104.334 CRDA
km 120.116 CRDA
km 120.556 SONEDE

To improve the reliability of the discharge measurements in the offtakes, the following methods shall be taken into consideration:

a) for all the nine pumped offtakes:
   - recalibration of the pumping stations
   - design of a flow measuring device in the offtake channel (figure 6)
     A selection can be made between a movable overflow structure, a venturi-flume or a Dethridge meter (if feasible).
   - installation of (acoustic) flowmeters in the pipes leaving from the pumping station

- set up of a waterbalance for each of the pools from which water is withdrawn

  $Q_0 = Q_1 - Q_2 - S$

  where

Q_0	offtake discharge
Q_1	discharge through the AVIO structure at the head of the pool
Q_2	discharge through the AVIO structure at the end of the pool
S	storage of water in the pool

  Q_1 and Q_2 can be calculated from the upstream waterlevel, the downstream waterlevel and the gate opening. Therefore the AVIO structure shall be calibrated by a model study.

b) for the three gravity offtakes:
   - design of a flow measuring device in the offtake channel
   - set up of a waterbalance for the pools from which water is withdrawn.

The need to improve the reliability of discharge measurements in the 12 offtakes is governed by the following factors:

a) is it possible to improve the measurements of inflow and transfer (pumping stations Bejaoua and Foundouk Jédid and Joumine pipeline)? The error shall be reduced to about 5%.
b) what accuracy is required: legally by the Ministry of Irrigation or by both parties concerned (SECADENORD at one side and SONEDE/CRDA at the other side)? As long as water is paid for a certain price, both parties should be interested in reliable flow measurements (error about 5%).

4.8 The overall waterbalance for the MCB canal

The waterbalance of the MCB canal - written in terms of volumes - is as follows:

$$V_{transp} = V_{withdr} + V_{leakage} + V_{storage} + V_{evap} - V_{precip}$$

where

V_{transp} volume of water taken in at El Aroussia + Joumine pipeline

V_{withdr} total of withdrawals by 12 offtakes

$V_{leakage}$ amount of water leaked through canal sections and aquaducts. This volume is unknown. It is expected to be low in comparison to V_{transp} and V_{withdr}.

$V_{storage}$ stored volume due to rise or fall of the waterlevels in the pools over the waterbalance period. For a long period $V_{storage}$ can be taken V = 0.

V_{evap} evaporated volume of water

V_{precip} volume of water from precipitation

} both can be calculated their contribution is expected to be less than 1%.

After some simplification the balance is rewritten as:

$V_{transp} = V_{withdr} + V_{losses}$.

SECADENORD prepares monthly and yearly reports of V_{transp} and V_{withdr} for the following canal sections:

- the section between the pumping stations Bejaoua and Foundouk Jédid (first section)
- the section between the pumping station Foundouk Jédid and the end of the canal (second section).

The annual report 1991 gives the following information on volumes of water (m^3):

production	V_{transp}	$V_{facture}$ (= V_{withdr}?)	V_{losses}
total prod.	117.104.241	113.158.183	3%
first section	55.547.046	50.745.762	8%
second section	52.054.080	52.909.306	-1%

During the mission there was no opportunity to get more information about the method along which the volumes V_{transp} and $V_{facture}$ have been calculated.

5. Conclusions, recommendations and cost assessment

5.1 Conclusions

The present mission focussed primarily on the appropriate flow measuring system on the Medjerdah Cap-Bon Canal, and further on associated items such as sedimentation in the canal and data collection.
Field visits have been carried out and discussions have been held with engineers of the Company for the Exploitation of the Canal and Northern Conveyors, SECADENORD.
It has been felt as a disadvantage that the mission period, April 26 through May 4, did not coincide with the period of full irrigation in the country. The discharges through the MCB canal were rather low. The behaviour of the AVIO automatic gates and the flow conditions in the offtakes could not be observed.

The main findings of the mission are summarized as follows:

o Transport of drinking water and irrigation water in the MCB canal is controlled by 20 AVIO automatic gates. Water is supplied on demand by downstream control. The proper performing of this system requires a minimum instability, which can best be checked in the period of full water demand.
  The AVIO gates have been introduced as flow regulating structures. There is no discharge relation available.
o All discharges through the canal are measured by the pumping stations Bejaoua (intake-discharge) and Foundouk Jédid, while the discharge from the Joumine pipeline can be estimated with a module à masque structure ($Q_{max} = 4\ m^3/s$).
  Particularly the calibration of the Foundouk pumping station is far from accurate. Both the instruments and the methods of discharge measurements with the velocity-area method can be improved. Actually the overall error in measuring the inflow discharge is between 10 and 20 percent.
o The withdrawn discharges in the existing 12 offtakes are measured and reported by the end-users SONEDE and CRDA. This is to be considered little strange, as the selling party SECADENORD has insufficient insight in the methods of discharge measurement, nor in their reliability.
  In nine offtakes the discharges are derived from the pumpcurves, while in

the remaining three gravity offtakes a large number of watermeters have been installed. Actually the overall error in measuring the withdrawals is between 10 and 20 percent.

- Sedimentation in the MCB canal is considered as a very serious problem. It causes a reduction of the canal capacity, it is costly and there is no sufficient place to store the dredged material on the banks.
  Three draglines are almost continuously cleaning the 120 km long canal from fine silt and clay.
- The results of all measurements in the field - waterlevels, pumping hours, turbidity and salinity - are transmitted to the SECADENORD head-office by radio, and then reported in books (not yet in a data base system).

5.2 Recommendations

All the recommendations given in this section aim at a better performance of the water distribution in the MCB canal.
Concerning the measurements of inflowing discharges as well as withdrawals, it is recommended to reduce the present overall error. This is important for SECADENORD, the water selling party, as well as for the paying end-users SONEDE and CRDA.
Concerning the sedimentation in the canal, it is recommended to reduce this as far as possible.
It is proposed to perform the recommended activities in two steps: the first phase and the second phase. For the majority of the proposed activities, technical assistance of experienced consultants is recommended.

1. **Measurement of discharges through the MCB canal and withdrawn from the MCB canal**

   Phase 1:

   a) a modern currentmeter for use in the field shall be bought in order to collect reliable discharge measurements for calibration purposes

   b) the pumping stations Bejaoua and Foundouk Jédid shall be recalibrated for which two weeks of technical assistance is recommended, including a check-up of the module à masque structure at the end of the Joumine pipeline.

If the recalibration of these three locations lead to a reduction of the losses in the waterbalance of the MCB canal, then the second phase can be omitted. But if the losses turn out to be larger, then the following activities are recommended:

Phase 2:

c) a study shall be carried out by SECADENORD with the technical assistance of a consultant, how to reduce the waterbalance losses. The main part of this study shall lead to suggestions how to improve the discharge measurements in the 12 offtakes. The technical assistance is expected to last about three weeks.

2. **Sedimentation in the MCB canal**

Phase 1:

a) a study shall be carried out by a consultant to evaluate the sedimentation in the canal: sampling and analysis of the sediments, followed by a preliminary advise, indicating different solutions how to reduce sedimentation. This technical assistance is expected to last about three weeks.

If the results of such a preliminary study do not lead to realistic solutions, then the second phase can be omitted. If they lead to a realistic (payable) solution, then the following activities are recommended:

Phase 2:

b) hydraulic design of an engineering solution to reduce sedimentation (for example the design of a silt-trap in one of the first pools of the canal), followed by an evaluation. This study will take about two weeks.

3. **Database for hydrological measurements**

Phase 1:

a) it is recommended to store all measured field data in a database, for which a consultant can write a software package and give a short course how to use the database. The duration of the consultant's activities will be about one week.

5.3 Assessment of approximate costs

The costs, mentioned in this section, include costs of technical assistance and the purchase of hardware and software. Distinction is made between phase 1 and phase 2. Phase 1 comprises all activities, recommended in section 5.2 to improve the present performance of the water distribution in the MCB canal. Phase 2 comprises activities which depend strongly on the results of Phase 1.

	Costs in US dollars Phase 1	Phase 2
1. Appropriate flow measurement systems		
a) purchase of a modern currentmeter	6000	
b) technical assistance calibration pumping stations and check-up module à masque (2 weeks)		
- travel and lodging	4100	
- fees (including preparation and reporting)	9900	
c) technical assistance for further reduction of waterbalance losses (3 weeks)		
- travel and lodging		5400
- fees (including reporting)		14600
2. Sedimentation in the MCB canal		
a) technical assistance sampling and preliminary advise (1 week Tunis + 2 weeks home)		
- travel and lodging	2800	
- fees (including reporting)	14600	
b) technical assistance: design work (1 week home), evaluation (1 week Tunis)		
- travel and lodging		2800
- fees		9900
3. Database for hydrological measurements		
a) purchase of software program	10000	
b) technical assistance for training (1 week Tunis)		
- travel and lodging	2800	
- fees	5200	
Total costs	55400	32700

Summarized costs: Phase 1 US$ 55,400
Phase 2 US$ 32,700
Total US$ 88,100

Abbreviations

DGECTH	General Directorate of Studies and Hydraulics Works (Ministry of Agriculture) Direction Générale des Etudes et Grands Travaus Hydrauliques
DGRE	General Directorate for Water Resources (Ministry of Agriculture) Direction Générale des Ressources en Eau
SONEDE	National Company for the Exploitation and Distribution of Drinking Water Société Nationale d'Exploitation et de Distribution d'Eau
SECADENORD	Company for the Exploitation of the Canal and Northern Conveyors Société d'Exploitation du Canal et des Adductiones du Nord
CRDA	Regional Commissariats for Agricultural Development Commissariats Régionaux au Développement Agricole

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ANNEX I: ITINERARY MISSION 'NORTHERN TUNISIA WATER RESOURCES MOBILIZATION AND MANAGEMENT PROJECT', TUNISIA, BY WUBBO BOITEN

April 26	Departure from Schiphol and arrival at Tunis	
April 27	a.m.:	visit with Mr. Velderman and Mr. Cottereau to the 'Direction Générale de Grands Travaux Hydrauliques' of the Ministère de l'Agriculture, director Mr. Khazen.
	p.m.:	visit to the Société d'Exploitation du Canal et des Adductions des Eaux du Nord, SECADENORD, director Mr. AAbdeljelil Ben Azouz, followed by a visit to the first Mornag offtake structure.
April 28	a.m.:	field visit to the El Aroussia Weir and diversion structures with Mr. Cottereau and Mr. Ghorbal of SECADENORD, followed by visits to the first regulation structure and the Bejaoua pumping station.
	p.m.:	visit to Tunis water supply offtake structure, and Foundouk Jédid pumping station.
April 29	Discussions at the office of SECADENORD with Mr. Ghorbal, Mr. Ezzeddine Ben Cheikh and Mr. Cottereau about the waterbalance of the MCB canal.	
April 30	a.m.:	reporting the impressions and discussions of the last two days
	p.m.:	final discussion with Mr. Abdeljelil Ben Azouz, director of SECADENORD.
May 1	Field visit to Joumine Barrage with seven team members of the mission.	
May 2	a.m.:	study of the report 'Rapport sur les travaux de réalisation du Canal Medjerdah Cap-Bon'
	p.m.:	visit to a sewerage station north of Tunis.
May 3	Day off, visit to Carthago.	
May 4	Departure from Tunis and arrival at Schiphol.	

The report of this preappraisal mission, including study and some computations, has been written within the period May 4 through May 11, 1992.