5 THE PROJECT

5.1 FUNCTIONS TO BE FULFILLED BY THE PROJECT

The Kandadji Dam has to be designed in way that it can meet all requirements as described below in an optimum way, seen from a technical as well as from an economical point of view:

- The dam's first objective is to close the valley to create a reservoir with sufficient storage capacity to meet the demands resulting from the simulation study of the reservoir operation (see Chapter 4).
- The difference between the maximum water level in the reservoir and the dam crest must provide a sufficient freeboard to prevent overtopping and to secure a safe operation, even under extreme conditions. The principal events that could cause a surge in the reservoir are the routing of floods through the storage, the wind set-up of the water surface and wave run-up at the dam's upstream face. To account for settlements after construction by maintaining the defined freeboard, it is common to build the crest of the dam higher than the design level, i.e. to provide camber.
- The dam must incorporate all necessary hydraulic structures for the release of the defined discharges from the reservoir into the downstream riverbed, required for low flow augmentation, irrigation, water supply for human consumption, livestock, industry and other users, even in the event that the hydropower plant is not under operation.
- A spillway must provide sufficient capacity to safely divert the design flood back into the river without exceeding the defined maximum water level in the reservoir. The design flood for Kandadji was calculated at 3,150 m³/s (see Chapter 3.2).
- Navigability on the river for pirogues (large canoes) must be maintained also after construction of the dam. Corresponding arrangements have to be made so that the transport of goods and people by boats is not interrupted.
- The continuity of transport between Tillabéri and Ayorou on the national road RN1 must be secured. Moreover, the dam will take over the function of a public bridge, giving access to the right bank zone of the Niger starting from the RN1.
- The reservoir must be impervious; i.e. the dam has to be designed in a way that no major seepage losses through the dam or below the dam foundation may occur.

A project concept was worked out that fulfils the conditions and requirements as listed above. It is described in the following Chapters 5.2 to 5.3. Some selected maps and plans are attached in the Annex to this report to better illustrate the project concept.

For more detailed information, reference to the individual reports is recommended.

5.2 DESIGN OF DAM AND APPURTENANT STRUCTURES

5.2.1 Dam Axis

The previous studies have convincingly shown that Kandadji is the most favourable site for the construction of a dam along the Niger River reach within the Republic of Niger, as at this site the Ourouba Hill on the right bank causes an exceptional narrowing of the valley. The Kandadji site is located in proximity of the village with the same name, 187 km upstream of Niamey and at 61 km downstream from the border between Niger and Mali. A few kilometres upstream from this site the tributary Gorouol joins the Niger; this widens the valley considerably and provides the potential for a reservoir of large capacity. Moreover, this site has the advantage of being located far upstream within the country, thus being able to supply all irrigable lands along the valley. This permits to achieve the highest possible benefit from the low flow augmentation.

The exact dam alignment, that was fixed within the scope of the present study, has the following characteristics:

- The dam axis could be kept linear along its entire length.
- On the left bank the dam axis reaches relatively high terrain (i.e. above the required dam crest level) at the shortest possible distance. Due to this favourable alignment, the ground along 53% of the dam length is above 220 m and along 76% above 215 m (the dam crest is on 231 m). This minimises the required quantities of construction materials and saves cost.
- The dam axis crosses the principal (right) arm of Niger River, where the hydropower plant, spillway and bottom outlet will be located, exactly perpendicular to the flow direction. This avoids an undesired diversion of the turbined or spilled flow.
- On the right bank, the axis is linked to the first of Ourouba's foothills, which rises in the direction of the axe to an elevation exceeding the dam crest.

5.2.2 Reservoir Dimensions

The characteristics of the reservoir are essentially determined by the maximum water level. Considering the findings of the simulation of the reservoir operation and taking into account all other important criteria for the selection of the maximum water level (within a possible range of 225 m to 230 m), a maximum reservoir level of 228 m was finally fixed (see Chapter 4.4). All technical planning was subsequently based on this maximum reservoir water level.

A new detailed planimetry of the reservoir area was carried out with the objective to derive the exact "Elevation - Area/Volume Curve" of the reservoir. For the maximum reservoir water level of 228 m a storage capacity of $1.597 \cdot 10^9$ m³ was calculated.

The freeboard makes up the vertical distance between the maximum water level in the reservoir and the dam crest elevation. The dimensioning of the freeboard takes account of the wind set-up caused by the wind-induced shear displacement of water towards one end of the reservoir and, in the event of storm, the run-up of waves against the upstream face of the dam. This wave run-up depends to a large extent on the slope of the upstream face and on its surface characteristics. The results of the freeboard calculation allowed drawing the following conclusions:

- The dam crest was fixed 3.00 m above the maximum reservoir water level of 228.00 m, i.e. on 231.00 m. Even in the event of high wind speed (up to 130 km/h), this freeboard would be sufficient to cope with wind set-up and wave action.
- Along the entire dam crest a parapet wall (wave wall) of precast concrete elements of 1 m height will be installed. This wall is shaped in a way that would turn waves, running up higher than the dam crest, back into reservoir.
- In this way the total freeboard amounts to 4.00 m, being sufficient even for extreme wind speeds up to 160 km/h.

5.2.3 Location of Structures

To put Kandadji Dam in a position to fulfil the defined objectives, it has to comprise the following individual structures:

- Principal dam structures:
  - main dam (earthfill dam)
  - spillway
  - hydropower plant
  - bottom outlet
- Appurtenant structures:
  - fish pass
  - intake for irrigation water
  - possibility for the transport of pirogues.

When establishing a new concept according to the revised project priorities, the basic important aspects to be considered were:

- Large use of construction materials locally available, i.e. covering the longest possible part by an earthfill dam and minimising the dimension of concrete structures, thus involving the highest possible amount of local labour during construction works.
- Reduction of number and dimensions of cost-intensive retaining walls as interface between the concrete structures and the earthfill dam section; for that reason, wherever possible, combining of concrete structures.
- Simple and secure operation, minimum maintenance requirements, longevity for all installations.
- Location of all project structures destined for water releases (hydropower plant, spillway, bottom outlet) in the present riverbed, thus avoiding the construction of special headrace and tailrace canal sections and maintaining the existing morphology of the River Niger.
- Minimising the rock excavation required for the foundation of the concrete structures.

This led to the development of the following project concept:

- All principal concrete structures of the project are grouped together in the following order (from right to left):
  - hydropower plant,
  - intermediate pier with fish pass,
  - bottom outlet,
  - spillway.

  This arrangement avoids any interface structure between the individual components. An earthfill dam covers the remaining dam length.
- The concrete structures are placed in the right arm of the river (main arm of the "lit mineur"), thus minimising excavation volumes for foundation.
- At the right side the concrete structures are directly connected to the Ourouba foothill. In this way only one transition structure at the left side will be necessary between the concrete structures and the earthfill dam.
- Two special transition blocks connect the concrete structures and the earthfill dam by extending the gravity dam profile of the spillway into the earthfill embankment. The upstream and downstream shoulders of the earth dam in the transition zone are returned and formed as quarter cones. This solution avoids the construction of special upstream and downstream retaining walls.
- Because of the limited navigation on the river, the high cost and technical efforts for a shiplock at Kandadji Dam cannot be justified. Instead, an inclined boatlift has been foreseen to allow pirogues to move from the reservoir to the downstream river and vice-versa.

For more details on the project concept and the arrangement and dimensioning of structures a reference to the individual reports is recommended. The major project components are shortly described in the following. A selection of plans and cross-sections that illustrates this solution is included in the Annex to this report.

5.2.4 Earthfill Dam

With regard to the available construction materials, an earthfill dam was the only dam type which could be taken into consideration.

The geological and geotechnical review (Chapter 3.5) has shown that the borrow areas provide three types of materials that could be used as dam fill, i.e. the "banco" (argillaceous, sandy silt), the "arènes argileuses" (highly silty, slightly argillaceous sand), and "arènes sableuses" (silty, gravelly sand). In order to achieve an economic solution and a short construction time, it was necessary to define the dam zoning as simple as possible, and the upstream and downstream slopes in a way to minimise the construction volumes, however, by considering all requirements resulting from the structural stability calculations.

The typical cross section of the earthfill dam is shown in Plan No. 5 in the Annex. The most important design features are:

- Dam Shoulders: The materials of higher quality in view of their permeability, i.e. argillaceous, sandy silt known locally as "banco" and highly silty, slightly argillaceous sand ("arènes argileuse") will be used for the upstream shoulder. The downstream shoulder can be also composed of silty, gravelly sand ("arènes sableuses"), as the demands on this part are less severe.
- Drains: In order to keep the line of seepage in the dam body on a low level and to discharge collected seepage water, vertical and horizontal drains drains are provided. The downstream dam shoulder is placed on a horizontal drainage blanket. A vertical chimney drain separates the upstream and downstream shoulders.
- Filters: Between the drains and the embankment materials, filters have to be installed to prevent erosion of fines into the drains.
- Riprap: The surface of both dam slopes are protected by riprap of large-sized rockfill to prevent erosion by wind, rain and – at the upstream side – wave action.
- Slopes: Under consideration of the soil mechanical parameters of the materials, the stability analysis defined the required inclinations for the upstream/downstream slopes with v:h = 1:3.0 and 1:2.5 respectively.
- Foundation: A foundation level at 2.00 m (on average) below the existing ground has been assumed as "normal" foundation level. In this way, it is expected that all highly permeable material is removed and a surface is provided which is sufficiently strong to support the dam.
- Cut off trench: For further seepage reduction, a cut off trench with a foundation of 2.00 m below the normal foundation level has been designed along the dam axis. The width of the trench is defined in relation to the dam height.
- Crest road: Over the entire length of the dam crest runs an asphalt covered service road.
- Drainage trench: A drainage trench runs along the downstream toe of the dam. It collects surface rainwater and seepage water from the drains and discharges it at topographical low points towards downstream.

Stability analyses for the selected design had been carried out by using the limit equilibrium method of "Bishop" to calculate the safety against slope failure. The results showed that sufficient stability is secured for all loads and load cases.

5.2.5 Spillway

As the reservoir of Kandadji Dam will be completely filled during 7 to 8 months per year, the spillway will have to be in operation whenever the inflow into the reservoir cannot be used simultaneously and entirely for energy generation in the hydropower plant. This frequent and long-term operation of the spillway requires special design care to achieve an irreproachable functioning, from a hydraulic as well as a technical point of view.

- Type of Spillway: In spite of all reviews and analyses in the field of climatology and hydrology, the future climatic development in the Niger Basin cannot be predicted reliably. Within the long operation period of Kandadji Dam, the occurrence of new climatic changes cannot be excluded; changes that could lead to increased flood discharges in the River Niger in an extent as it could not sufficiently be taken into account with pure historic analyses. A good spillway design must also consider this (improbable) eventuality in a way that an operation of the spillway with discharges higher than the design discharge is principally possible, without putting the dam security at risk. These reflections led to the selection of an overfall type spillway and definitely exclude all spillway types with low level outlets, as proposed in the previous studies.

- Dimensions: Only relatively long overfalls with stilling basins of corresponding widths can reduce the unit flow (flow per meter of width) in a way that the excavation depth for the stilling basin remains reasonable and the flow can be diverted back into the natural riverbed without transition canals. The hydraulic calculations showed that eight openings, each with a width of 17.50 m, are required for the spilling of the design flood of 3,150 m³/s.
- Gates: It goes without saying that ungated overfalls have great benefits with regard to their low cost, their simplicity of reservoir level regulation without human intervention, and their functional security, nearly without the risk of failures. However, their disadvantage lies in the fact that the storage volume between the overfall crest level and the maximum flood water level cannot be exploited. For a given maximum water level in the reservoir, the active storage capacity becomes thus inevitably smaller.
  The results of the simulation of the reservoir operation have shown that the entire storage capacity up to the elevation of 228 m will be required to secure a minimum flow of 120 m³/s during the low flow season. Water levels above 228 m are excluded to avoid the inundation of territories in neighbouring countries. Therefore the spillway has to be equipped with gates. The great length of the spillway openings in relation to their height offers ideal conditions for the installation of flap gates. They involve the great advantage that in an emergency case they can be opened (i.e. lowered) without energy supply. As they divert the discharge over the gate, they are very suitable for the regulation of the reservoir water level and less vulnerable to clogging due to floating debris.
- Stilling Basin: The frequent and long use of the spillway makes high demands on its hydraulic efficiency and operation security. Best suited is a conventional stilling basin that fixes the hydraulic jump and dissipates the excess energy. The resulting subcritical flow at the downstream end of the stilling basin is diverted back into the riverbed.

5.2.6 Bottom Outlet

The bottom outlet is an essential structure of the Kandadji Dam. It provides a hydraulic capacity that assures the required water releases from the reservoir into the downstream riverbed during the period of low flow augmentation, the subsequent controlled annual reservoir re-filling, the control and - if necessary – the draw down of the reservoir water level in case of emergency, and an eventual spilling of floods in combination with the spillway. However, it must be noted that during dam operation all water releases from the reservoir will be effected preferably by the hydropower station in order to generate electricity.

As the bottom outlet can only be a concrete structure, it is best combined with the other concrete structures, i.e. the spillway and the hydropower plant, and located in the main river arm (right arm). Due to the low level of its opening and the high flow velocities, the bottom outlet should be moved away from the earth dam to avoid the risk of erosion. Thus it is best arranged between the spillway and the hydropower plant.

In order to achieve economic dimensions of the regulating and service valves, the required total cross section for the opening is distributed to three individual outlets. The total capacity of the bottom outlet amounts to 420 m³/s (at a reservoir level of 223 m). One block with a width of 20 m proved to be sufficient to accommodate the three outlets, the same width that had been selected for the spillway blocks.

5.2.7 Transition Blocks between Earthfill Dam and Spillway

The contact zone between earthfill and a concrete structure must always be considered as a potential zone of weakness, the conception of which necessitates particular attention to avoid all risk of cracking and piping failures due to differential settlements. The proposed solution avoids the construction of special upstream and downstream retaining walls by the arrangement of two special transition blocks with a length of 40 m that extend the gravity dam profile of the spillway into the earthfill embankment. For that purpose, the standard profile of the earthfill dam stops 40 m before reaching the spillway block. Starting from this point, the upstream and downstream earthfill embankments take the form of quarter cones in which the transition blocks penetrate. Due to the conical form, sufficient structural stability is secured for even the final part of the earthfill dam, thus avoiding the construction of any retaining wall.

5.2.8 Fish Pass and Intermediate Pier

An artificial dam structure presents an obstacle for the natural seasonal migration of fish in the river. According to internationally recognised standards, provisions for a fish pass have to be made to avoid injury to fisheries. In the case of Kandadji, this fish pass will be integrated in the intermediate pier that separates the hydropower plant from the bottom outlet. In principal there are three kinds of fish passes, that differ by their way of functioning: the fish ladder, the fish lift, and the fish lock. For reasons which are explained in the individual report (Phase II, Vol. 1), a fish lock proved to be the best adapted solution for the Kandadji Project.

5.2.9 Irrigation Intake

Independent of the large release structures in the minor riverbed ("lit mineur") that divert the water into the downstream riverbed, an additional small water intake for irrigation purposes is provided on the left bank near the national road RN1. Here it can be linked most directly and with gravitational force, i.e. without pumping station, to the main irrigation canal supplying the perimeters between Kandadji Dam and Tillabéri.

5.2.10 Lift for Pirogues

The transport of goods and persons on the river, though limited, should not be interrupted by the Kandadji Dam. It is expected that after implementation of the project river navigation on the Niger will increase, as the reservoir extending to the Mali border will form an excellent traffic route. The project will also improve the navigation conditions in the downstream river section due to low flow augmentation.

The project concept of the previous studies included the construction of a shiplock for pirogues, which, with a maximum lift of 18 m, would become an important and consequently extremely costly structure. Considering the essential objective of the present study, namely to achieve cost savings by a simplification of the project concept and a reduction of the structural dimensions, it was decided, in view of the limited traffic volume, to omit the shiplock and to assure the transport of pirogues from the reservoir to the downstream river reach and vice-versa by an inclined boat lift.

5.3 DESIGN OF HYDROPOWER PLANT

5.3.1 Basic Data for the Exploitation of the Hydropower Potential

The generation of hydroelectric energy by the Kandadji Dam is subordinated to the priority objectives of the project, i.e. low flow augmentation, securing the perenniality of irrigation, and water supply for human consumption, livestock and industry. Consequently the definition of the reservoir operation and the determination of the minimum discharge during the low flow season were done exclusively under consideration of ecological and water supply aspects. Thus, an optimisation of the reservoir operation in view of energy generation was not realised.

The series of the flow releases from Kandadji Dam for the characteristic period of 1966-1998, resulting from the optimisation of the reservoir operation (see Chapter 4), served as basic input for the simulation of hydroelectric energy production.

The predicted development of electricity demand in Niger (see Chapter 3.11) was also taken into consideration.

5.3.2 Design Optimisation of the Hydropower Plant

The optimisation of the Kandadji Hydropower Plant is a complex combined technical-economical process that is based on a comparison of the costs of the plant and the benefits resulting from it. The costs of the hydropower plant are composed of the costs for the civil works and for the hydromechanical and electrical equipment. The benefits arise in form of generated energy. An optimum conception is characterised by a minimum Cost/Benefit-Ratio.

With regard to the essential necessity of frequency control for stabilising the electrical network in Niger, only a Kaplan type turbine proved to be suited for the plant.

The further optimisation of the hydropower plant was carried out in three stages, namely:

- 1st Stage: Optimisation of the total installed capacity
- 2nd Stage: Optimisation of the number of units
- 3rd Stage: Optimisation of the specific speed.

The first Stage Optimisation Process analysed installed capacities in a range of 100 MW to 140 MW. With regard to the predicted demand of 100 MW in the Year 2015 (with a trend towards further increase), a total installed capacity 125 MW was recommended. In order to adapt the energy production to the predicted demand development and to reduce the initial investment cost, the implementation could be done in two phases: Phase I with a total installed capacity of 100 MW, that would satisfy the demand up to the Year 2015, and a subsequent extension by 25 MW, resulting in a total capacity of 125 MW in Phase II.

The second Stage Optimisation provided the best results for a scheme with a total number of five units. With this alternative, each unit would have a capacity of 25 MW and a nominal flow of 190 m³/s. The following Table 5-1 summarises the features of the recommended scheme:

	Phase 1	Phase 2	Phases 1+2
Total installed capacity (MW)	100	25	125
Number of units (-)	4	1	5
Total turbined discharge (m³/s)	760	190	950

Table 5-1: Recommended design features for the hydropower plant

The optimisation process in the third Stage showed that a specific speed of 103.45 min^{-1} for the turbine gives the most economic figures.

Thus the findings of the optimisation can be summarised as follows:

- Type of turbine: Kaplan
- Total installed capacity: 125 MW
- Number of units: 5
- Turbine specific speed: 103.45 min^{-1}
- Total nominal discharge: 950 m³/s
- Nominal turbine flow: 190 m³/s

5.3.3 Design Concept of the Hydropower Plant

The conception of the hydropower plant was carried out on a feasibility design level and based on the results of the optimisation. Furthermore, technical design criteria to secure an undisturbed and long-term operation were defined and applied to the design. Apart from a harmonious integration of the plant in the overall project, principal emphasis was given to technical and economical considerations. The design shows the following salient features:

- Location of the plant: on the right side in the main arm of Niger River ('lit mineur')
- Number of blocks: 6 (5 units + 1 erection bay)
- Total length: 114 m
- Total width: 50.50 m
- Crest height: 231.00 m

A typical cross section of the hydropower plant is given in Annex 7 of this report. For more detailed information on the design concept, reference should be made to the individual report (Phase II, Volume 2).

5.3.4 Cost and Benefit

The investment costs for the hydropower scheme, the total installed capacity, the mean annual energy production and the specific cost per installed capacity were determined as follows:

	Phase 1 (4 units)	Phase 2 (1 unit)	Phases 1 + 2 (5 units)
Investment cost	82.5 million €	10.4 million €	92.9 million €
Total installed capacity	100 MW	25 MW	125 MW
Mean annual energy production	488.7 GWh/a	75.7 GWh/a	564.4 GWh/a
Specific cost per installed capacity unit	825 €/kW	416 €/kW	743 €/kW

Table 5-2: Hydropower Plant, cost and benefits

The following Figure 5-1 shows for an average year the typical development of the power available at Kandadji Hydropower Plant compared to the predicted energy demand for the Years 2010 and 2015.

It appears that the energy demand can be completely covered during the months of October to February. However, for the period of March to September, the power demand must be partly satisfied by other resources, i.e. by energy imports from Nigeria or by the implementation of gas, fuel or coal-fired thermal plants.

5.4 HYDRO-AGRICULTURAL DEVELOPMENTS

5.4.1 Selected Cropping Patterns

The valley of the Niger River has been subdivided into three zones divided as follows:

- a North Zone which spreads from the Mali border to Kakomani,
- a Central Zone which extends from Kakomani to Kirtachi,
- a South Zone which goes from Kirtachi to the Nigerian border.

Table 5-3 hereunder provides the proposed cropping pattern for each of the three zones and their corresponding intensities.

Zones	Basins				Terraces			
	Dry season	**Rate** (%)	**Wet season**	**Rate** (%)	**Dry season**	**Rate** (%)	**Wet season**	**Rate** (%)
North Zone	Rice	100	Rice	100	Sugarcane Cassava Maize	60 10 30	Sugarcane Cassava Maize	60 10 30
Central Zone	Rice	100	Rice	100	Arboriculture Vegetables Niébé seed	10 30 60	Arboriculture Vegetables Niébé seed	10 30 60
South Zone	Rice Maize Sorghum	70 15 15	Rice Maize Sorghum	70 15 15	Peanut Cotton	50 50	Peanut Cotton	50 50

Table 5-3: Cropping patterns

The suggested crop rotations appear to be most adapted to the existing conditions, namely the cultural practices, the agro-industry, the storage and transport facilities and the market demand. However, these crop rotations will have to be constantly adapted to respond to the evolution of the nutritive needs of humans and animals and also to the market demands.

A range of crop successions and rotations have been suggested on the terraces of the Niger River banks, taking into consideration the results of the various experiments developed by concerned research institutes as well as the yield of the tested crops.

5.4.2 Water Demand

The water requirements of each crop are a function of the climate conditions of the period in question and also of the crop and its vegetative state during that period. Table 5-4 shows the monthly requirements per hectare for the crop rotation of the basins and terraces of the North, Central and South Zone of the river valley.

Zone	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
North:													
Basins	1,544	2,274	2,646	1,020		540	1,415	1,090	1,610	825		1,220	**14,184**
Terraces	1,198	1,420	1,610	1,400	1,533	1,511	1,347	886	1,280	647	705	791	**14,329**
Centre:													
Basins	1,772	2,766	3,366	1,240		590	1,210	1,390	1,830	1,140		1,220	**16,524**
Terraces	1.546	1,694	1,158	578	417	1,353	958	815	422	321	419	1,389	**11,070**
South:													
Basins	1,779	2,351	2,313	728		252	770	394	683	515	243	1,240	**11,268**
Terraces	1,734	1,976	1,783	714	227	347	575	261	529	501	233	861	**9,739**

Table 5-4: Monthly irrigation water demand per hectare (m^3/ha/month)

The annual requirements increase from around 9,739 m^3/ha and 11,268 m^3/ha for the terraces and basins of the South Zone to 11,070 m^3/ha and 16,524 m^3/ha for those of the Central Zone and 14,329 m^3/ha and 14,184 m^3/ha for those of the North Zone.

5.4.3 Proposed Development Programme

The suggested development programme concerns a total of 31,000 ha of new lands by the year 2034 as follows:

- An area of 16,275 ha will be developed into terraces,
- A total surface of 14,725 ha will be exploited in the basins.

The distribution by irrigation system follows:

- Large developments irrigated by open channels: 13,950 ha,
- Large developments irrigated by pressurised system (Système Californien): 3,100 ha.
- Large developments irrigated by controlled flooding: 1,550 ha.
- Development of the small irrigation on a surface area of 12,400 ha.

Development Components

The main components of the suggested development consist of:

- Pumping stations to serve the basins and terraces by delivering water from the river,
- Small pumps to serve small irrigation projects,
- Irrigation channels or pipes; the primary channels are in concrete while the secondary and tertiary are in earth,
- Distribution networks consisting of pipes or channels (concrete or earth),
- Surface and sub-surface drainage networks,
- Dykes for protection against floods,
- Construction works (bridges, culverts, side weirs, etc.),
- Hydro-mechanical and hydro-electrical equipment for the management and control of the water distribution networks,
- Access and maintenance tracks,
- Electricity networks,
- Management premises.

Phasing of Construction

The development rate will depend on the remedy of the constraints that confront the agriculture sector in Niger and on the initiation of the training programmes, the institutional reforms and other support programmes. The rate for the future construction of the hydro-agricultural schemes is 1,000 ha/year (see Table 5-5).

The programme based on the annual implementation of the 1,000 ha from 2004 to 2034 is distributed into 600 ha of large irrigation and 400 ha in small irrigation taking into account the national politics in terms of irrigation development.

The 600 ha of large irrigation are divided in the following:

- 450 ha for irrigation by open channels,
- 100 ha for irrigation by pressurised systems (Système Californien),
- 50 ha for irrigation by controlled flooding.

Except for the last system exclusively developed in basins and the second system in terraces, the surface area for irrigation by open channels will be justly divided between basins and terraces. So will be the 400 ha allocated to small irrigation.

Following this hypothesis, some 525 ha and 475 ha will be respectively developed every year into terraces and basins and be well distributed between the 3 zones (North, Central and South). Therefore a total of 16,275 ha in terraces and 14.725 ha in basins will be implemented between 2004 and 2034.

Year	Large Irrigation Schemes (ha)			Small irrigation schemes (ha)	Total (ha)
	Open canals	**Pressurised systems**	**Controlled flooding**		
2001	-	-	-	-	-
2002	-	-	-	-	-
2003	-	-	-	-	-
2004	450	100	50	400	1,000
2005	450	100	50	400	1,000
2006	450	100	50	400	1,000
2007	450	100	50	400	1,000
2008	450	100	50	400	1,000
2009	450	100	50	400	1,000
2010	450	100	50	400	1,000
2011	450	100	50	400	1,000
2012	450	100	50	400	1,000
2013	450	100	50	400	1,000
2014	450	100	50	400	1,000
2015	450	100	50	400	1,000
2016	450	100	50	400	1,000
2017	450	100	50	400	1,000
2018	450	100	50	400	1,000
2019	450	100	50	400	1,000
2020	450	100	50	400	1,000
2021	450	100	50	400	1,000
2022	450	100	50	400	1,000
2023	450	100	50	400	1,000
2024	450	100	50	400	1,000
2025	450	100	50	400	1,000
2026	450	100	50	400	1,000
2027	450	100	50	400	1,000
2028	450	100	50	400	1,000
2029	450	100	50	400	1,000
2030	450	100	50	400	1,000
2031	450	100	50	400	1,000
2032	450	100	50	400	1,000
2033	450	100	50	400	1,000
2034	450	100	50	400	1,000
Total	**13,950**	**3,100**	**1,550**	**12,400**	**31,000**

Table 5-5: Phasing of hydro-agricultural developments

5.5 COSTS OF DAM AND HYDROPOWER PLANT

The total construction costs were estimated on the basis of an established bill of quantities and unit prices derived from the Consultant's own cost database compiled from large international dam and hydropower projects. In order to account for the economic peculiarities in Niger, special emphasis was given to projects in West Africa, especially concerning the supply of construction materials and the price of local labour. The costs for hydromechanical and electrical equipment correspond to the regular international price level for similar equipment.

A cost summary is presented in the following Table 5-6. All prices are indicated in Euro (€) on a price level of April 2000 (1.00 € = 656 Francs CFA) and are shown without taxes.

5.6 COST OF HYDRO-AGRICULTURAL DEVELOPMENT

The investment and replacement costs as well as the maintenance, operation and power costs for the various proposed developments are shown in Table 5-7.

The cost of the technical support varies from one project to another and has been estimated at an average of 10% of the total investment costs.

Type of development	**Area** (ha)	**Cost**			
		Investment	**Replacement**	**Operation**	**Electricity**
		million FCFA	million FCFA	million FCFA up to 2034	million FCFA up to 2034
Open canal networks	13,950	89,367 *(6,4 /ha)*	3,620	16,805	8,182
Pressurised systems	3,100	17,011 *(5.5 /ha)*	1,609	3,458	1,818
Controlled flooding	1,550	5,425 *(3.5 /ha)*	-	814	-
Small irrigation	12,400	20,150 *(1.6 /ha)*	8,100	3,953	5,840
Total	**31,000**	**131,953**	**13,329**	**25,030**	**15,840**

Table 5-7: Costs of proposed hydro-agricultural developments

6 ENVIRONMENTAL IMPACTS

6.1 GENERAL

The assessment of the environmental impacts of the Kandadji dam was established based on the approach recommended by the World Bank and was formulated around the following:

- Take into consideration the present environmental state and the increasing tendencies towards drought and desertification, especially in the no-project case;
- Provide a global view of the scale and diversity of the potential impacts of the project;
- Indicate possible mitigation measures which would be necessary following the construction of the Kandadji Project;
- Show how alternative project options could eventually allow the modulation and alteration of the project's impacts and the need for corresponding mitigation measures.

Thus, a wide range of project impacts has been identified in the physical, biological as well as the human environments, the principal conclusions of which are described in the following paragraphs.

6.2 BIOPHYSICAL IMPACTS

6.2.1 Hydrology - Hydrogeology

The proposed project will have a well-marked impact on the hydrological systems:

- The dam site is located 61 km from the frontier with Mali and 187 km to the north of the Niger's capital Niamey. The project will therefore exert a certain control on approximately 500 km of the river inside Niger.
- The operation zone (situated between the dam axis and the point from which the river regains its natural flow) will be very limited, in the order of 0.5 km;
- The downstream flow will be maintained in a significant manner upholding a minimum flow of 120 m³/s and the proposed management of the future reservoir will only have limited influence on the river floods. This is due to the fact that the total reservoir capacity is quite low, in the order of 1.6 billion m³, representing only between 5% and 8% of the annual flows.
- The Kandadji dam will have a negligible influence on the annual river flow in Nigeria. On the other hand, the augmentation of low flow provided by the dam (120 m³/s at Niamey) will certainly have beneficial fallouts for the Niger River in Nigeria.
- Groundwater recharge will be expected upstream at the reservoir (infiltration) as well as downstream from maintaining a minimum flow level during the dry period.

6.2.2 Sedimentation

The average long-term sediment transport in the Niger at the future Kandadji reservoir has been estimated at 2 to 3 x 10^6 tons/year, based on field investigations undertaken within the scope of the present study. This is considered relatively low and as such, the loss of reservoir capacity due to sedimentation is not problematic. The loss in storage capacity is estimated at 7% after 50 years and at 13% after 100 years. The life expectancy of the Kandadji dam would be longer than 300 years, which is fundamental for a project that would have to ensure the sustainability of water resources of the River Niger valley for a long period.

Furthermore, the process of sustaining a minimum water level during low flow season by maintaining a minimum flow of 120 m³/s will contribute against silting of the river downstream of the dam, that constitutes under the present conditions a serious threat to the Niger River, its pertaining activities and for the fluvial ecosystem in general:

- The rise of the minimum water levels during the dry period will allow for the creation of new wet zones along the Niger River valley and will thus increase the humidity level and the natural fertility of soils. These factors favour the regeneration of the natural vegetation, which would reduce soil erosion and desertification.
- The possibility of water table recharge by infiltration from the reservoir and the maintaining of a minimum water level in the downstream reach of the Niger River support the development of the vegetative cover, thus reducing erosion and silting up of the river.

6.2.3 Bio-diversity

Despite the weakness in database, it is considered extremely improbable that a significant reduction in the regional bio-diversity occurs following the project execution. On the contrary, substantial advantages in maintaining high humidity levels in the flood plain downstream of the dam site in addition to the creation of a new ecosystem (reservoir) can be expected in the long-term. The project will maintain and even increase the size and diversity of the natural resources. The loss of habitats/biotopes in the reservoir zone might be significant, but the advantages brought to other habitats, especially those located downstream, as well as the potential reinforcement of their associated functions and services will largely compensate the negative aspects.

A certain number of species which are locally rare and important on the international level (endangered species) utilise the habitats which will undergo a total change or significant modifications. The relative importance of such effects is unknown and should be the subject of specific studies and evaluation.

New environmental surroundings will be created as follows:

(a) the reservoir aquatic habitat,
(b) extensive wet zone area,
(c) delta flooded systems,
(d) disrupted habitat of the operational zone, and
(e) wet zones of the major bed resulting from the submersion of the alluvial plain (floods) and its widening during dry season (maintaining a minimum water level).

From the fish resources point of view, the proposed regulation by the Kandadji dam will preserve on one hand the fishery stock as well as the productivity of the area in the long-term and on the other hand reinforce the development of pisciculture (in ponds and/or in cages) in sites downstream of Kandadji that are presently threatened by the variability of the river flows. Moreover, the reservoir, due to its important volume and water depth (28,200 ha for an average height of 5.6 m), offers an opportunity for development of pisciculture in cages.

Finally, the construction of the Kandadji dam will contribute against desertification by:

- The reduction of the progressive degradation to which the natural resources are presently subject to (due to overgrazing and cutting of branches from trees for animal feeding), by improving the river's water potential and mainly by securing better fodder availability.
- The regeneration of the vegetative cover due to the creation of new humid zones along the river valley and the recharge of ground water.

6.2.4 Water Quality

Most factors indicate a very low phosphorous content and an initially ultra-oligotrophic reservoir. The reservoir banks should experience a weak productivity whereas the inner lands are largely sterile. The relatively small volume that percolates out of the reservoir and the little man-made activities in the reservoir lead to the assumption that the water quality in the reservoir should remain good.

On the other hand, significant changes of the water quality in the downstream areas are expected. Indeed a net improvement in water quality is expected due to the aeration (release of water from the reservoir) as well as to the dilution of the pollution discharged by the river bank agglomerations (especially the city of Niamey). This will lead to the significant increase in the purification capacity of the river and the regeneration of the fluvial ecosystem.

6.2.5 Ecological Risks

The threat of invasion of the water hyacinths of the Kandadji reservoir and the risk of increased infestation of the downstream areas are not insignificant. In the light of the experience of other African countries it is practically certain that there will be a prolific development of the water hyacinths in the lake which will probably pose serious problems if the situation is not well managed from the start.

As for the eutrophication, in absence of human activities within the reservoir as well as data related to the transboundary transport of pollution (domestic, industrial and agricultural wastes), the risk is considered limited.

6.3 SOCIO-ECONOMIC IMPACTS

6.3.1 Resettlement of the Population

The most significant negative impact of the project is the need to move population from the area of the future reservoir. It is estimated that around 35,000 people located in 15 administrative villages would have to be resettled following the construction of Kandadji dam.

6.3.2 Infrastructure Flooding

It is foreseen that the construction of the Kandadji dam will only cause a very limited loss of infrastructure. The presently known impacts appear as follows:

- A section of around 43 km of the national road (RN1) needs to be reconstructed.
- From the 11 villages in the reservoir area, the following infrastructures will be inundated:
  - 7 boreholes,
  - 3 community clinics,
  - 12 schools,
  - 30 mosques,
  - 2 slaughterhouses,
  - 2 traditional markets,
  - 2 mills.

6.3.3 Loss of Agricultural Lands

An area of around 7,000 ha of agricultural lands, of which 210 ha are for the Firgoun hydro-agricultural development, will be flooded by the future Kandadji reservoir.

6.3.4 Guarantee of Water Supply

There is no doubt that the most important aspect of the project resides in satisfying the water demand for all users even under worst drought conditions, namely:

- The supply of drinking water to Niamey, Tillabéri and the riverside villages, particularly under consideration of the prevailing unfavourable hydro-geological conditions which exclude the use of groundwater;
- The irrigation of the potential agricultural lands and maintaining the natural productivity of the wet zones;
- The water demand of the industrial and livestock sectors;
- The rehabilitation of the existing fish farms and the development of new ones.

6.3.5 Reduction of Dependence on Energy Imports

From the energy point of view, it is clear that the construction of the Kandadji dam can only generate positive impacts, namely the reduction of dependence on energy imports, specially bearing in mind that Niger's energy demand is growing. The dam will also allow the development of other activities that will be feasible with water availability and cheaper energy.

6.3.6 Nutritional Security and Sustainable Development

Through maintaining the valley and fluvial ecosystem's natural productivity as well as meeting the various water needs advantages would be expected in the mid and long-term. This will contribute to the improvement of the nutritional security and the economic condition, subject to the implementation of a rational strategy.

At fish resources level, it is expected that:

- The fishing conditions will be favourable at the level of the proposed reservoir compared to the controlled catches reported by the statistical post of Ayorou (138.4 tones in 1998), of around 1,447 tons, namely a turnover of around 868,000,000 FCFA.
- Job opportunities will be created.
- A reinforcement of the development of fishing activities, presently hindered by the high charges related to water pumping, will be seen.
- In the long-term, the development of the fishing potential and the downstream pisciculture is an option for controlling the fishing efforts and the migratory flows at the reservoir level to ensure a sustainable development of this sector.

With regards to the livestock sector, the construction of the Kandadji dam will imply the following effects:

- The availability and improvement of the fodder resources;
- An increase in number of heads and animal production, namely with the opportunity of developing the current raising method towards the intensive type with the introduction of more performing exotic breads.
- The creation of jobs, the alleviation of conflicts, the reduction of the degradation of natural resources and the keeping of animals in one site instead of transhumance seasonal move.
- The disappearance of the sedentary isolated raising and of certain transhumance tracks in the reservoir zone. However, the importance of this barrier effect is very limited due to the fact that the bridge over the future dam will allow for the movement of livestock from one bank to the other, as well as, in particular, the promotion of the economic activities linked to breeding between the two important regions of the North (Tillabéri and Téra) for which at present no crossing point exists (apart from the ferryboat).

On the agriculture side, the following is expected:

- Development of a potential of 31,000 ha;
- Alleviation of the constraints linked to the availability of water (guarantee of 2 campaigns per year and the reduction of pumping charges);
- The possibility of an integrated management plan within a framework of sustainable development;
- An improvement in the production based on agricultural diversity and reasonable agriculture;
- The contribution to nutritional security.

6.3.7 Public Health

It is clear that the construction of the Kandadji dam will lead to a major public risk due to the creation of biotopes favourable to the development of water-related diseases and of transmission sites.

On the other hand, the improvement in the availability of high quality water in the downstream zone will have a positive impact, thus reducing infections and faecal diseases.

6.3.8 Other Indirect Impacts

The construction of the Kandadji dam will be accompanied by a number of indirect impacts, namely:

- The accessibility of the region (no crossing point exists presently);
- The contribution to the reduction of rural migration;
- The development of industrial activities upstream as well as downstream of the hydro-agricultural developments;
- Job opportunities during construction and following new activities;
- The improvement of the fluvial traffic by maintaining a minimum water level in the river;
- The easier access to groundwater;
- The contribution against desertification.

6.4 ENVIRONMENTAL MANAGEMENT PLAN

An Environmental Management Plan (EMP) was developed for the Kandadji project and consists of four main components:

- The Construction Management Plan;
- The Mitigation Plan;
- The Environmental Monitoring Programme;
- The organisation and reinforcement on the Institutional Plan.

The total cost of the EMP would be quite substantial, probably not less than 100 million US$ for a 16 year period:

Phase	Cost (million US$)
Pre-construction Programme	75
Construction Programme	2
Post-construction Programme	23

6.5 CONCLUSION

Considering the present conditions of drought and the methods of use of resources in the Niger River basin, the environmental diagnostic highlighted the decline of productivity of the natural and artificial production systems, which will severely reduce food availability on the regional and local scale in the mid and long-term. Consequently, it is expected that such effects will exert a strong pressure on the social structures which govern the region's activities, and lead to massive movement of the population and loss of social cohesion.

Assuming more negative conditions linked to the possible climatic changes, the relatively high level of biodiversity and productivity in the Niger River valley will be even further reduced to the point where a large number of activities, which are presently practised, can no more persist. In such circumstances, the rapid collapse of the social systems becomes highly probable.

In this context, the Kandadji Project is considered as an essential infrastructure investment in the scope of a mitigative strategy destined to ensure the long-term availability of the water resources, which are of paramount importance for the survival of the human communities and the Niger River valley's productivity. The project therefore cannot simply be considered as a typical development project which could be assessed on the basis of costs and benefits over a 30-year period, whatever figures are taken into consideration.