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Independent review of the Environmental Impacts Assessment Report (EIAR) 2005 on the future Ilisu Dam (Turkey)

Prepared for

Erklärung von Bern - Berne Declaration

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1. Introduction

A full consideration of environmental impacts is generally required at the planning stage of dam construction on major rivers. Construction companies are therefore required to prepare or contract an environmental impact assessment report (EIAR) in accordance with specific guidelines, generally addressing three major topics:

Social issues**:** the consequences of resettling people living in the area to be flooded;
Archeological issues**:** the destruction or submerging of important archeological sites;
Environmental issues: the effect of large-scale hydrological alteration of the natural river system with major impacts on the environment and water quality.

Such is the case of the Ilisu Dam Project on the Tigris River in southeastern Turkey, for which a new EIAR was completed in 2005 by the Ilisu Environment Group[1] (IEG), improving upon a previous EAIR (2001) prepared by the IEG[2].

In January 2006, Eawag was contracted by the Berne Declaration (Erklärung von Bern) to provide an independent review of the EIAR (2005), appraising whether the anticipated impacts were satisfactorily described and their extent adequately estimated by the new EIAR. For the social and archeological issues, we did not have the competence to make any remarks or recommendations. Focusing on the environmental issues only, and relying on the sparse database presented by the EIAR (2005), this review

(i) crosschecked and reevaluated the degree of some physical aspects for which the predictions were vague, confusing or appeared to be incorrect (i.e. sedimentation, reservoir lifetime, evaporation, greenhouse gas emissions and impounding period); and

(ii) quantified the extent of several parameters with crucial roles on the environment and water quality (i.e. primary production, eutrophication, nutrient cycle, oxygen depletion or thermal stratification) which were identified by the EIAR 2005 as a possible consequence of the Ilisu project but which were not calculated. Our findings are listed in tables at the end of each subchapter, and the main conclusions regarding the EIAR (2005) are summarized at the end of the report.

IEG[1] composed of Hydro Concept Engineering (Switzerland), Hydro-Québec International Inc. (Canada) and The Faculté Universitaire des Sciences Agronomiques of Gembloux (Belgium).

IEG[2] composed of Hydro Concept Engineering (Switzerland), Hydro-Québec International (Canada), Colenco (Switzerland), and Dolsar (Turkey).

2. Conclusions

General Remarks

- The present independent evaluation of the environmental impacts of the future Ilisu Project **suffers from a lack of data and information.** The minimum information that was provided was **often vague, incomplete or contradictory**. Without a solid base, the accuracy of this independent evaluation suffers from a large degree of uncertainty. However, we performed the assessment with the information provided to the best of our ability, and within this limitation.
- Many of the key environmental issues such as reservoir water quality, downstream effects or sedimentation were briefly discussed by the EIAR (2005) at a theoretical level, **but no reliable assessment of their impacts has been made**. Without knowing the degree of impacts, appropriate solutions for minimizing the effects may be difficult to establish.
- Considering the dam location, close to the Syrian-Iraqi border, the impacts of the Ilisu Dam construction on downstream hydrology, water quality and sedimentation should not be considered as only of local importance as it will also directly affect riparian areas. **Therefore, in the assessment of environmental impacts, transboundary impact analyses should be performed.**
- By storing the annual runoff of the Tigris River, the construction and the operation of the Ilisu Dam will **significantly affect the present natural hydrology and significantly reduce the downstream flow in Syria and Iraq**. If the irrigation in Turkey will be supported by the annual water storage in the Ilisu Reservoir, the regulation of the Tigris flow is **anticipated to have major impacts on the recession farming along the river in Syria and Iraq**.

Reservoir-Induced Seismicity

- **Even though the creation of the reservoir is not viewed as a potential hazard, the assessment of hypothetical dam failure due to higher seismic activity or accidents on large downstream populations appears nevertheless advisable.**

  In all reported cases of reservoir-induced seismicity, there were existing historically active faults in the area of the reservoir. But only three documented cases have recorded seismicity greater than 6 on the Richter scale: at Xinfengjiang in China (1962), at Kariba in Central Africa (1963) and at Konya in India (1967). A number of faults with east-west direction cross the Ilisu Reservoir area and earthquakes with a magnitude of 6 are anticipated by the EIAR (2005) in the vicinity of the dam site. Therefore, possible cases of reservoir-induced seismicity with magnitudes below 6 are not considered an issue for the Ilisu project.

Sedimentation

- Large **uncertainties** exist in the EIAR (2005) **concerning estimates of reservoir sediment retention**.
- **The values for sediment capture or riverine sediment loads presented by the report vary within one order of magnitude**. As we were unsuccessful in re-evaluating this issue due to a lack of data, we estimate a sediment retention capacity of the Ilisu Reservoir up to 95% of the incoming load.
- The volume of sediment annually retained in the reservoir is expected to reach up to 95 % of the incoming load. For a broad scale variation on sediment loads presented by the report, the storage capacity of the reservoir may by lost in relatively short time, varying between 150 and 400 yr, according to our calculations.
- **The volume of sediment retained annually in the reservoir is expected to be substantial.** As water reaches the inflow, coarse sediment will be deposited at the upper part of the reservoir where a delta can form in a relatively short period. One possible solution would be mechanical removal of the accumulated sediment, but this would probably be costly. **Financing the appropriate maintenance of the reservoir may be difficult**.
- **High sedimentation rates in the reservoir are expected to smother the benthic organisms with enormous quantities of silt deposited in the lake.**
- The **sediment and nutrient trapped in the reservoir will induce downstream erosion possible causing a decrease in aquatic productivity and automatically a decrease in fish yield downstream.** Changes in turbidity may affect the biota directly. This reduction can also lead to **the elimination of backwaters that provide aquatic habitat for native species and the reduction of riparian and wetland vegetation.**
- **Low sediment load passing through the dam will result in erosion being the dominating process downstream. Scouring of the river bed as a result of low sediment loading and high water velocities (narrow river channel) can result in significant alterations of the adjacent water table**.

Water Quality

- **High riverine nutrient loads reaching the Ilisu Reservoir will trigger the onset of eutrophication**. Even if proposed waste water treatment plants and reduction of nutrient loads are implemented, **internal processes within the reservoir will keep concentrations at the eutrophic level.**
- The bottom water release from the Ilisu Reservoir will **result in downstream coldwater pollution which together with low dissolved oxygen concentration in the discharged water during the summer are expected to have major impacts on the downstream fish population.**
- Decreased turbidity near the dam, due to particles tending to settle in the upper part of the reservoir, will increase light penetration.
- High nutrient availability together with a stable summer thermal stratification will **increase the algal productivity in the reservoir.**
- A residence time of more than half a year will allow large portions of the biomass to degrade within the water column, reducing the oxygen level to total depletion and **increasing greenhouse gas emissions**.
- In the absence of oxygen, sedimentary organic matter mineralization will lead to methane production, releasing large amount of nutrients into the water column.
- Stored in the hypoliminion as a result of summer stratification, mixing processes between hypolimnion and epilimnion during late autumn and winter will increase the nutrient pool favoring high rates of primary production up to 700 g C m^{-2} yr^{-1} able to fix between 70,000 and 200,000 t C yr^{-1} annually. From this, up to 7,000 and 22,000 t C yr^{-1} will be available in the sediment of the Ilisu Reservoir for annual CO_2 and CH_4 production.

➢ **Stratified and oxygen depleted waters are not suitable for fish or other organisms. Fish and their eggs will not be able to survive in the deep water of the reservoir. Together with high sedimentation rates, this may result in total extinction of benthic organisms in the reservoir area.**

Hydrology and Water Balance

- Significant alterations on the hydrological regime of the Tigris River will occur with the construction of the Ilisu Dam. Eliminating the downstream annual flooding which flushed and cleansed the river once a year, the Ilisu Dam will store the seasonal runoff in a 10.4 km^3 reservoir for hydropower production and irrigation.

- Failing a water agreement between Turkey, Syria and Iraq, a minimum flow release during impounding takes into consideration only the downstream agricultural need and water supply requirements of Turkey. **No transboundary impacts are considered**.
- The simulation of **the impounding period** performed by the EIAR (2005) for average flow years and wet years, seems to be generally **lower than our estimates**, by a factor of two (for average discharge years) and three (for wet years) respectively.
- After the impounding phase, the dam operation scheme will focus on power production which will ensure a discharge close to the present annual flow.
- With a present requirement of 1.2 km^3 yr^{-1}, the irrigation scheme will use more than 6% of the river inflow and increase in the future up to 12%. As 15% of this water is predicted to return to the reservoir, increased N and P, and **a rise in reservoir salt content is therefore expected.**
- Additional hydrological alteration will appear in the near future with the new dam construction at Cizre.
- The amount of water lost annually through evaporation from the reservoir area (up to 5% of the reservoir volume) will be compensated for by the annual input via precipitation and therefore, for the overall balance can be considered negligible. Evaporation will increase the reservoir salt content.

3. Project Description

3.1. Tigris River in Turkey

- Length: 385 km
- Drainage area: 41,000 km^2 + 15,000 km^2 beyond the Turkish border in Iraq
- Average discharge at Ilisu: Q = 502 m^3 s^{-1} (15,842 M = 15.84 km^3 yr^{-1})
- Half of discharge occurs between March and May (the rainy season) and the maximum runoff is spread from November through May. From May to June the high flow is contributed to by the snow melt.
- Highest discharge: April at Cizre: Q=1,400 m^3 s^{-1}
- Driest month: Sept. at Cizre: Q=115 m^3 s^{-1}
- Max. flow in 1966: Q=8600 m^3 s^{-1}
- Main tributaries: Batman, Garzan and Botan
    - Tigris at Diyarbakir (6,078 km^2): mean annual flow of 2.2 km^3 yr^{-1}
    - Batman River (4,871 km^2): mean annual flow of 4.4 km^3 yr^{-1}
    - Garzan River (2,759 km^2): mean annual flow of 1.6 km^3 yr^{-1}; mean annual suspended load of 1.5-2.5 Mm^3 yr^{-1}
    - Botan River (10,654 km^2): mean annual flow of 4.5 km^3 yr^{-1}; mean annual sediment load of 5-10 Mm^3 yr^{-1}
    - Tigris at Rezuk (34,623 km^2): downstream from the confluence with Botan; mean annual flow of 15 km^3 yr^{-1}; mean annual sediment load: 15-30 Mm^3 yr^{-1}
    - Tigris at Ilisu (35,517 km^2): mean annual flow of 15.524 km^3 yr^{-1}
    - Tigris at Cizre (38,295 km^2): mean annual flow of 16.6 km^3 yr^{-1}
- Present irrigation needs: 1,050x10^6 m^3 yr^{-1} (1.05 km^3 yr^{-1}) accounting for 6.6% of the inflow of 15.8 km^3 yr^{-1} assuming a 15% water return
- Future needs: 1,910x10^6 m^3 yr^{-1} (1.9 km^3 yr^{-1}) as 12.1% of the inflow
- Present irrigated land: 1,400 km^2
- Total future irrigated land: 2,650 km^2

3.2. Ilisu Dam

- 45 km upstream from Cizre and about 80 km upstream from the Syrian border
- 135 m high
- 1820 m crest length
- Volume: 43.8 Mm^3
- Install capacity: 1,200 MW, 6 Frencis turbine units of 200 MW
- Energy production: 3,833 GWh

- Spillway design for a maximum discharge of 18,000 $m^3 s^{-1}$ at Maximum Water Level. The sill of the spillway is 15 m below the Normal Water Level.

3.3. Ilisu Reservoir

- Area at Maximum Water Level of 526.8 m (a.s.l.): 313 km^2
- Area at Normal Water Level of 525 m (a.s.l.): 300 km^2
- Area at Minimum Operating Level of 485 m (a.s.l.): 100 km^2
- Volume (storage capacity)
    - Inactive (Dead Storage): 2,959 Mm^3 (2.95 km^3)
    - Active (Live Storage): 7,460 Mm^3 (7.46 km^3)
    - Total Storage: 10,410 Mm^3 (10.41 km^3)
- Average annual inflow: 15,450 $Mm^3 yr^{-1}$ (15.45 $km^3 yr^{-1}$)
- Reservoir length: 135 km, Average discharge: 490 $m^3 s^{-1}$
- Early drawdown: 8-10 m
- Minimum Operation Level (485 m): 40 m below the Normal Water Level (525 m)
- Reservoir catchment area: 35,517 $km^{2,}$
- Air temperature: -9 to 48 °C
- Average precipitation: 814 mm (0.814 m),
- Average evaporation: 1,695 mm (1.695 m)
- Water release during reservoir impounding
    - From April through October: $Q_{min} = 60\ m^3 s^{-1} + 0.5x(Q_{inflow}-60)m^3 s^{-1}$
    - From November through March: $Q_{min} = 100\ m^3 s^{-1}$

3.4. Definitions

Normal Water Level: The highest reservoir level normally permitted, which can be exceeded up to the Maximum Water Level only in the case of a large flood occurrence.

Minimum Operating Level (Drawdown Level): The lowest level at which the power plant can still operate without risk of damage. Not to be confused with the "early drawdown" representing the minimum water levels reached each year.

Inactive Storage (Dead Storage): The volume of the reservoir below the Minimum Operating Level, filled at the beginning of the reservoir impounding period. This volume cannot be considered for power plant operation nor for water releases downstream.

Active Storage: The reservoir volume between the Minimum Operating Level and the Normal Water Level, representing the volume of water available for energy production including the minimum water flow needed for the release downstream in case this release would not be controlled by the power plant alone.

Total Storage: The sum of the Inactive and Active Storages.

4. Environmental Impacts

4.1. Reservoir-Induced Seismicity

Even though there are still many discussions concerning the processes that trigger seismic activities in man-made reservoirs, there are two basic mechanisms on which most scientists agree: (i) the additional stress on the underlying formations caused by filling the reservoir, related to the volume of the water in the reservoir; and (ii) increased pore water pressure along faults, depending on the water levels in the reservoir above pre-reservoir groundwater levels (Abu Zeid 1995).

It is generally accepted that water weight or pressure cannot cause earthquakes in areas not subjected to previous seismic activity. In all reported cases of reservoir-induced seismicity, there were existing historically-active faults in the area of the reservoir. Only three documented cases have recorded a seismicity greater than 6 on the Richter scale: in China (at Xinfengjiang 1962), Central Africa (at Kariba in 1963) and the largest known reservoir-induced earthquake in India at Konya in 1967 with a magnitude of 6.5 on the Richter scale, causing more than 200 deaths (Adams 1983).

From the experience of other cases, reservoir-induced seismicity may occur at the Ilisu Reservoir within the first few years after reservoir impounding (filling). Even so, it is unlikely that the magnitude of possible earthquakes will go beyond 6 on the Richter scale, which is the maximum credible earthquake design for the Ilisu Dam. Therefore, although earthquakes with a magnitude lower than 6 are possible, reservoir-induced seismicity does not appear to represent an issue for the Ilisu Project.

Major Findings: Seismicity	
1.	**Reservoir-induced seismicity is expected to appear after a few years following impounding.**
2.	**For magnitudes below 6 on the Richter scale, an induced seismic activity may not represent an issue for the project.**

4.2. Sedimentation

One of the main environmental issues resulting from impounding a river system characterized by a large catchment area and rapid waters is represented by the large volume of sediment trapped annually behind the dam. Besides influencing biogeochemical processes within the reservoir, this will considerably reduce the reservoir's storage capacity, in a relatively short period, and increase downstream erosion.

Assessing the sediment balance for the Ilisu Reservoir, page 3-11 of the EIAR (2005) used an empirical formula ($Q_S = 13.959*A^{1.213}$, where A is the drainage area in km^2) to calculate a sediment volume up to 4,619,000 m^3 yr^{-1} being collected annually from the catchment area of 35,517 km^2. Part of this sediment is correctly assumed to be trapped in the upstream existing dams, but no estimation of the retention capacity for Ilisu is done. Moreover, even correctly assuming that the contribution of the bed load of the Tigris River to the total sediment load is negligible (in general, for large rivers, the overall contribution of the bed load to the total sediment load is only few percent), the EIAR (2005) characterized and calculated the bed load in more detail than the suspended load. However, two scenarios were assumed by the EIAR (2005) to have a major impact on sediment capture:

- ***Category 1***: Five upstream projects in operation, under construction or at the "final stage" with a total area of 7,181 km^2. Considering this, the report predicted that: *"the volume of sediments produced and transported would be in the order of 3,285,000 m^3/year and correspond to a sedimentation rate of 122 m^3/year km^2 in the Ilisu reservoir."*

Our calculation: That the sediment yield will be reduced by only 30% from five additional upstream projects seems to be too low. However, if subtracting the area of 7,181 km^2 from the Ilisu catchment (35,517 – 7,181 = 28,336) and using the above empirical formula, the sediment volume would reach about 3,512,000 m^3 yr^{-1} and not 3,285,000 m^3 yr^{-1} as reported by the EIAR (2005). Furthermore, dividing by the area of 28,336 km^2, the sedimentation rate would be 124 m^3 km^{-2} yr^{-1} and not 122 m^3 km^{-2} yr^{-1} as predicted by the EIAR (2005).

- ***Category 2***: Another five projects in planning or "reconnaissance" with an additional area of 5,052 km^2 out of which only 30% will become implemented in the near future. Considering all 10 projects, the sedimentation was predicted to decrease to 119 m^3 km^{-2} yr^{-1}.

Our calculation: 30% of the 5,052 km^2 represents 1,515 km^2. Subtracting from the above calculated area of 28,336 km^2 and using the empirical formula, the annual sediment volume would indeed reach 3,285,000 m^3 yr^{-1} or a sedimentation rate of 122 m^3 km^{-2} yr^{-1} as calculated by EIAR (2005) for Category 1.

These are only small variations, however, as the difference between the two expected sediment volumes at the Ilisu up to 227,000 km^{-3} yr^{-1} is only 5% of the initial load of 4,619,000 m^3 yr^{-1}. The real concern is related to sediment estimates which seem to be incorrect and inconsistent with the latter data. A few points below may help explain our concern:

(1) In general, the weight of Total Suspended Solids (TSS) in water varies between 1.77 and 1.86 metric tons per m^3 (of g cm^{-3}) and the weight of dry TSS samples varies between 2.57 and 2.83 t m^{-3}. The bulk density of freshly-deposited sediment based on a composition of 30% sand, 40% silt and 30% clay as described by the EIAR (2005) is about 1.4 g cm^{-3} but a compaction factor is needed. This problem is solved using an average sediment density of 1.56 g cm^{-3} which includes the correction for compaction (dry weight density of 2.6 g cm^{-3} and a porosity of 40%). Therefore, the volume of 3,285,000 m^3 yr^{-1} accumulating annually in the reservoir would correspond to a mass of 5,125,000 t yr^{-1} of sediment. Dividing this load by the average annual inflow of $15{,}450 \times 10^6$ m^3 y^{-1}, the TSS concentration reaches 162 g m^{-3} and seems reasonable. This sediment mass of 5,125,000 t yr^{-1} ascribed to be deposited in the Ilisu Reservoir is practically a factor of 2 higher than the latter simulated inflow sediment load of 2,540,000 t yr^{-1} (Enclosures 2, page 23). A reservoir cannot practically retain more sediment than is brought in by the inflow. Better would be to use an average TSS concentration (in g m^{-3}) which together with the water flow (in m^3 yr^{-1}) would give the annual sediment load at the reservoir inflow. Further, the sediment retention capacity can be predicted as a function of the reservoir residence time (see point 3 below). Practically no TSS concentrations are available in the entire report and the few data reported are for the upper stretch of the river.

(2) We tried to calculate the inflow load gathering data on the TSS inflows from a list of main annual suspended loads at different locations along the Tigris River (page 3-14 and 3-15). The mean sediment load of the Tigris River downstream from the confluence with the Botan River is described by the EIAR 2005 (page 3-15) to vary

between 15 and 30 Mm^3 yr^{-1}. As "Mm^3" represents "million cubic meters" (10^6 m^3), the suspended load is therefore varying between $15x10^6$ m^3 yr^{-1} and $30x10^6$ m^3 yr^{-1}. Please note that the sediment load "*produced and transported*" to the Ilisu given earlier by the EIAR (2005) was $4.6x10^6$ m^3 yr^{-1}. However, using a sediment density of 2.6 g cm^{-3} (assuming dry weight), the average volume of $22.5x10^6$ m^3 yr^{-1} (mean value between 15 and 30 $x10^6$ m^3 yr^{-1}) converts into a mass of $58x10^6$ t yr^{-1}. This is one order of magnitude higher than the previous simulated load of $2.5x10^6$ t yr^{-1}. Even using the density of fresh sediment of 1.8 g cm^{-3}, the sediment load will reach $40x10^6$ t yr^{-1}. Why this discrepancy, and which one is the correct value? If compared to the annual sediment load of the Nile River at Aswan Reservoir inflow of $142x10^6$ t yr^{-1}, the sediment load of $58x10^6$ t yr^{-1} for Ilisu, even at a factor of 2 to 4 lower, is in the same order of magnitude and therefore seems to be right. But the Nile River has an average water inflow of $84x10^9$ m^3 yr^{-1} with gives an average TSS concentration of 1,700 g m^{-3}, already considered to be a high value. For the Tigris River, with an annual water flow of $15.45x10^9$ m^3 yr^{-1}, the TSS concentration for the dry mass would correspond to 3,700 mg l^{-1} or 2,600 mg l^{-1} for the wet sample density. Even if not impossible, these high concentrations are unlikely for such a river system. This conclusion is supported by the maximum reported TSS concentration for the Batman River of 240 mg l^{-1} (Table 3-2, page 3-3). With this concentration and a mean annual flow of 4.4 km^3 yr^{-1}, the TSS load for the Batman River reaches 10^6 t yr^{-1}. Unfortunately, no data on TSS load is given in the EIAR (2005) for this tributary and therefore, the correctness of this value cannot be verified.

(3) At the bottom of page 4-33, it is mentioned that *"as observed in other large reservoirs in Turkey, the suspended load will almost completely settle in the reservoir"*. We fully agree with this sentence. The sediment retention capacity of a reservoir can be easily estimated from the slowdown of the water reaching the impoundment. To calculate the average water velocity in the Ilisu Reservoir, we use the relationship between the volume (V) and the discharge (Q) which lets us estimate the residence time (τ) or the time required by the inflow water to reach the outflow:

$$\tau \text{ (yr)} = V \text{ (km}^3\text{)}/Q \text{ (km}^3 \text{ yr}^{-1}\text{)} = 10.41/15.45 = 0.67 \text{ yr} = 8 \text{ months} = 246 \text{ days}$$

Knowing that the reservoir length at Normal Level will be 135 km, the average water velocity in the Ilisu Reservoir will decrease to about 0.635 cm s^{-1}. A residence time of 4.5 days and a main stream velocity of 34 cm s^{-1} resulted in the case of Iron Gate I Reservoir (Danube River) with a TSS retention of up to 56% of the incoming load (Teodoru and Wehrli 2005). For a residence time of 2.7 years which corresponds to a water velocity of 0.016 cm s^{-1}, the TSS retention in Lake Brienz (Switzerland) was calculated as 97% of incoming load (Finger et al. submitted). Water velocities of about 0.8 cm s^{-1} for Aswan High Dam Reservoir (Egypt) were responsible for sediment retention of 96 to 98% (Shalash 1982). A linear correlation between the cases mentioned above was used for the Merowe Reservoir to estimate a retention capacity of up to 92% of the incoming sediment load, resulting in a drop of water velocity from 40–80 cm s^{-1} down to 4.3 cm s^{-1} at the time of dam completion (Teodoru et al. 2006). In the case of Ilisu, a water velocity of 0.6 cm s^{-1} would result in retaining up to 96% of the sediment inflow load (see Figure 1).

Therefore, 96% of the incoming sediment load will be trapped in the newly-forming Ilisu reservoir. This is in agreement with the EIAR (2005) assumption of almost complete settling of the suspended load.

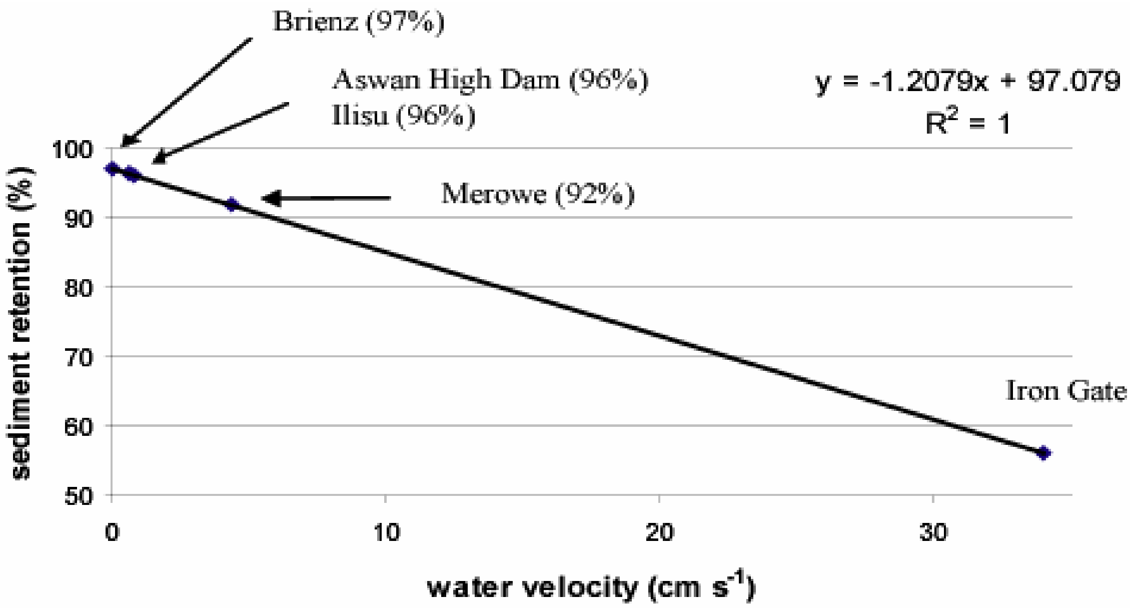

Figure 1

However, the missing parameter to calculate the total amount of sediment annually trapped in the Ilisu Reservoir is the TSS inflow load.

(4) For a TSS inflow load of 58×10^6 t yr^{-1} (dry weight) or 40×10^6 t yr^{-1} (fresh sediment) and a retention capacity of 96%, the total sediment trapped annually in the reservoir would reach 56×10^6 t yr^{-1} or 38×10^6 t yr^{-1} respectively, whereas using their simulated inflow load of 2.54×10^6 t yr^{-1}, the mass of sediment retained annually would be 2.4×10^6 t yr^{-1}. Therefore, with an average sediment inflow of 22.5×10^6 m^3 yr^{-1} and an annual retention capacity of 96%, up to 21×10^6 m^3 yr^{-1} will accumulate in the Ilisu Reservoir, or only 1.5×10^6 m^3 yr^{-1} if using the EIAR (2005) predicted inflow load, respectively.

(5) The lifetime of a reservoir represents the time until the reservoir fills up with sediment, losing its storage capacity. This can be calculated by dividing the reservoir storage volume by the accumulation rate. If 3.3×10^6 m^3 yr^{-1} sediment (as in EIAR 2005) is considered to be trapped annually behind the Ilisu dam, the Dead Storage capacity of the reservoir of $2{,}959 \times 10^6$ m^3 will be lost in about 890 years and would take another 2,200 years until the Total Storage capacity is completely lost. Usually, the lifetime of relatively small reservoirs reaches a few hundred years but not thousands. For instance, the lifetime of the Dead Storage capacity of the huge Aswan Reservoir is about 360 years, and will take up to 1,000 years before the Aswan loses its active capacity. The lifetime of the Ilisu Reservoir based on the annual accumulation of 3.3×10^6 m^3 yr^{-1} may be too high, and therefore the sediment trapped annually behind the dam must be much higher. If considering an annual sediment accumulation of 21×10^6 m^3 yr^{-1}, the reservoir will lose its Dead Storage capacity in 140 years and its Total Storage capacity in an additional 355 years. For a sediment volume of 1.5×10^6 m^3 yr^{-1}, (corresponding to a mass of 2.5×10^6 t yr^{-1}) the time requirement is in the order of thousands of years: 1,970 and 4,970 years respectively.

Therefore, regarding the sedimentation issue, it is still not clear which of the three values found in the EIAR (2005) represents the real situation. Most probably, the closest value to the real situation is somewhere between 3.3×10^6 m^3 yr^{-1} and $15\text{-}30 \times 10^6$ m^3 yr^{-1}.

Major Findings: Sedimentation	
1.	**A sediment yield of 3.3x10^{6} m^{3} yr^{-1} was calculated by the EIAR (2005) from the catchment area based on an empirical formula.**
2.	**An inflow sediment load of 2.5x10^{6} m^{3} yr^{-1} was also predicted by the EIAR (2005) based on model simulation. This inflow load is actually lower than the total reservoir accumulation.**
3.	**A load of between 15 and 30x10^{6} t m^{3} yr^{-1}, one order of magnitude higher than previous values was later reported by the EIAR (2005) to represent the sediment load of the river at the dam site. This load is also described in the old EIAR (2001).**
4.	**No dataset on suspended solids concentration is available to estimate which value should be considered closer to the real situation.**
5.	**Based on residence time we were able to predict a retention capacity of up to 96% of the incoming load. Using an average sediment load of 22.5x10^{6} m^{3} yr^{-1} annually, up to 21x106 m^{3} yr^{-1} can be accumulated in the Ilisu Reservoir.**
6.	**No assessment of the impacts from such sedimentation was done by the EIAR (2005) for the reservoir itself nor for the river downstream.**
7.	**No prediction for an important physical parameter – reservoir lifetime – was done by the EIAR (2005). According to our calculations, the reservoir lifetime will vary between 100 and 400 years.**

4.3. Water Quality

4.3.1. Thermal Stratification

A common effect of river impoundment in arid or semi-arid areas is the onset of thermal stratification of the reservoir water column. Thermal stratification in natural lakes depends on external driving forces such as hydro-meteorological conditions, location, wind-induced surface forces, etc. and internal properties such as lake morphometry (surface, shape and depth), light absorption and the theoretical water residence time, function of reservoir volume and flow. The variations in the water level are important for the mixing of the lake water column and the distribution throughout the reservoir of the water during seasonal floods. The extent of the flood and penetration-depth distribution will determine the general pattern of thermal stratification.

The onset of thermal water column stratification is expected in the Ilisu Reservoir. Thermal stratification was also mentioned in the EIAR (2005) but no estimates were made. An empirical dependence of reservoir stratification on residence time (τ) to the maximum temperature difference between the surface and hypolimnion was found by Straskraba and Mauersberg (1988) for several reservoirs in the Czech Republic, approximated by the equation:

$$\Delta T_{0\text{-}30} = 20\ (1\text{-}\exp\ (-0.0126 * \tau))$$

According to this formula, with a residence time (τ) of about 246 days, the temperature difference between surface and hypolimnion (down to 30 m for the Ilisu Reservoir) will correspond to a maximum of about 19°C. This should not be taken as an accurate value, but rather as an estimate of the upper limit.

Consequently, the reservoir water column will probably become stratified over the entire reservoir length during the summer period. During the flood period, the thermal stratification may be disrupted, especially on the upper stretch of the reservoir. The extent of vertical convection throughout the reservoir and the pattern of disturbance of the thermal stratification will depend upon the initial water level in the reservoir and the hydrological conditions of the flood. With a maximum reservoir length of 135 km and a water depth of over 100 m in front of the dam, it is unlikely that the entire volume of the Ilisu Reservoir will be subject to thorough mixing during the flood period. However, the changes in climatic conditions during the winter period will result in the overturn and mixing between epilimnion and hypolimnion, allowing dissolved oxygen to penetrate the depths of the reservoir down to its floor.

Thermal stratification	
1.	**The onset of thermal stratification is mentioned in the EIAR (2005) but no estimate of the extent of this parameter was made.**
2.	**Using an empirical formula based on the water residence time, we were able to predict, with large uncertainty, an upper limit temperature difference of 19°C between the surface and 30 m depth during the summer period.**
3.	**It seems probable that the stratification will be disrupted during annual floods, but a minimum stratification will be maintained for the reservoir area in front of the dam. During the winter, a mixing process between surface and deep water is expected due to overturn, supplying oxygen to the hypolimnion and increasing the surface nutrient pool.**

4.3.2. Nutrients

The N and P concentrations in the surface water are described on page 3-17 as:

- Inorganic nitrogen ($N\text{-}NO_3$+$N\text{-}NO_2$+$N\text{-}NH_4$): average 3.5 mg l^{-1} with a maximum value of $N\text{-}NO_2$ up to 13 mg l^{-1}
- Inorganic phosphorus (PO_4): 0-0.53 mg l^{-1}, average 0.24 mg l^{-1}; it is not clear if it is PO_4 or $PO_4\text{-}P$

Later on, on page 4-38, nutrient concentrations are given for several stations along the Tigris River. The nitrogen concentrations increase from 2 mg l^{-1} upstream from the city of Diyarbakir to about 5.5 mg l^{-1} below the confluence with the Batman River and progressively decrease to about 2.4 mg l^{-1} at a site around 20 km upstream from the dam, whereas at Cizre the concentrations increase again to 2 mg l^{-1}. Phosphorus also shows local variations with an increase from 0.3 mg l^{-1} upstream from Diyarbakir up to 1,100 mg l^{-1} below Bismil, with a low concentration of about 0.2 mg l^{-1} below the confluence with Batman River, an increase downstream up to 0.6 mg l^{-1} followed by a decrease down to 0.03 mg l^{-1} close to the dam and more than 0.1 mg l^{-1} at Cizre (see Figure 2). This large local variation in nutrient concentrations along the Tigris River is believed to represent the cumulative effect of domestic waste water discharge from major cities, irrigation and industry. A few questions arise here: (1) Given those high concentrations in the upper reaches of the river, why are the concentrations so low at the reservoir site? Carried downstream by the river, the concentrations should increase accordingly; (2) Is this a dilution effect or is the river's self-purification capacity so high? It would be useful to see the data plotted together with the water discharges.

However, average concentrations calculated over the last four stations of 2.7 mg l^{-1} N and 0.22 mg l^{-1} P are even lower than the previous concentrations listed on page 3-17. It is also not clear if phosphorus values from Figure 2 are given as PO_4, $PO_4\text{-}P$ or total P.

The EIAR (2005) is aware of high nutrient concentrations along the entire stretch, and places the Tigris River in the high eutrophic level (>30 µg P l^{-1} and 650 µg N l^{-1}), but no effort is made to quantify the impact of nutrient loading on water quality issues in the newly-forming reservoir, estimating the range of primary production, the extent of oxygen depletion, nutrient cycle, greenhouse gas emissions or subsequent downstream-related impacts.

The major sources of high-nutrient input from the catchment are considered to be upstream agriculture (irrigation), domestic waste water discharge from major cities such as Diyarbakir, Bismil, Batman and Siirt (which release a cumulative rate of domestic waste water of about 3.7 m^3 s^{-1}) and industrial waste water. A short water residence time of 0.67 years as in the case of Ilisu may result in a slow increase in nutrient concentration of up to 5% at the beginning of reservoir impounding. However, the changes in nutrient concentration within the reservoir will largely depend on the input, and to a lesser extent on the internal processes.

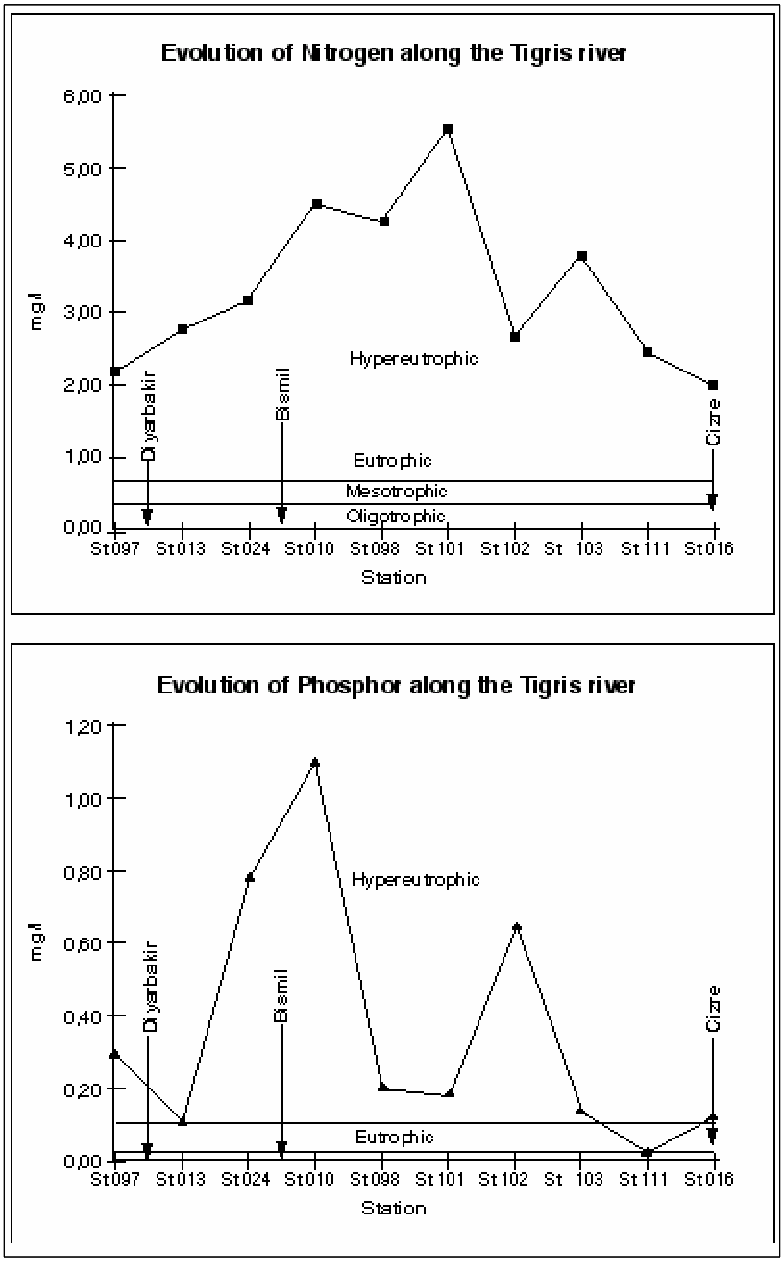

Figure 2

With the current average concentrations of 3.5 mg N l^{-1} and 0.24 mg P l^{-1} and an annual water discharge of 15.45 km^3 yr^{-1}, the inflow loads would reach about 54,000 t N yr^{-1} and 3,700 t P yr^{-1} respectively. The expected increase of 5% resulting from internal processes will contribute annually with an additional 2,700 t N yr^{-1} and 200 t P yr^{-1}, respectively. Also, a large amount of organic matter is expected to be brought in each year by the river inflow. Assuming a Redfield molar ratio of 106C:16N:1P, the inflow organic carbon load would range between 150,000 and 300,000 t yr^{-1}.

Depending on the dam operation scheme, lower water release, especially during the impounding phase, will contribute to increases in the reservoir's nutrient content.

Major Findings: Nutrients	
1.	**High nutrient concentrations in the entire stretch of river and at the dam site are reported by the EIAR (2005) but no quantification of the impact of high nutrient loading on water quality and internal biogeochemical processes (such as primary production, oxygen depletion, nutrient cycle, greenhouse gas emissions or subsequent downstream-related impacts) has been done.**
2.	**Using the EIAR (2005) stated concentrations of 3.5 mg N l^{-1} and 0.24 mg P l^{-1}, we were able to calculate an annual nutrient load of 54,000 t N yr^{-1} and 3,700 t P yr^{-1} respectively. We also predict an annual incoming load between 150,000 and 300,000 t yr^{-1} of organic carbon.**
3.	**From a residence time of 0.7 years, we predict an annual increase in reservoir nutrient concentrations up to 5%. This implies that the availability of nutrients in the reservoir will be mainly dependent on the incoming loads and to a lesser extent on internal processes. However, as predicted by the EIAR (2005), to decrease during the coming period due to implementation of waste treatment plants, the nutrient loads will still go high up into the eutrophic level.**

4.3.3. Limiting Factors for Primary Production

Before estimating the extent of primary production, a good exercise may be to identify its limiting factor, for which phosphorus concentration is a good indicator. Considering the values given as PO_4-P:

$$360\ \mu g\ PO_4\ l^{-1} \leftrightarrow 117\ \mu g\ P\ l^{-1} \leftrightarrow 3.7\ \mu mole\ P\ l^{-1}$$

According to the Redfield molar ration of 106 C: 16 N : 1 P, during photosynthesis for every atom of phosphorus assimilated, 16 atoms of N are also assimilated and 106 atoms of carbon fixed into organic matter. If all phosphorus would be consumed during primary production, a concentration of about 60 µmole N l^{-1}, or 840 µg N l^{-1}, would be required. As the nitrogen concentration of 5,200 µg N l^{-1} is actually six times higher, P may be the limiting factor in reservoir productivity. Even if the phosphorus values are given as PO_4-P (360 µg P l^{-1} ↔ 11.5 µmole P l^{-1}), the nitrogen required during primary production up to 2,590 µg N l^{-1} is still a factor of two lower than the present concentration. Therefore, phosphorus may be considered the limiting factor for reservoir productivity.

4.3.4. Primary Production

The equivalent carbon fixation due to the total P assimilation as calculated above may result in a primary production rate between 240 g C m^{-2} yr^{-1} (if 360 µg l^{-1} is given as PO_4) and 720 g C m^{-2} yr^{-1} (if 360 µg l^{-1} is given as P). The same range of primary production rates can be expected from the figure below, which shows the relationship between P concentration and primary production measured is several lakes in Switzerland (Figure 3). For a reservoir area of 300 km^2 at the Normal Water Level, the carbon fixation in the Ilisu Reservoir will range between 72,000 t yr^{-1} and 216,000 t C yr^{-1}, corresponding to a total organic matter production of between 180,000 t yr^{-1} and 450,000 t yr^{-1}. These values represent the *in-situ* carbon produced within the reservoir, without considering the large amount of organic carbon predicted earlier to be transported annually from upstream areas by the river inflow.

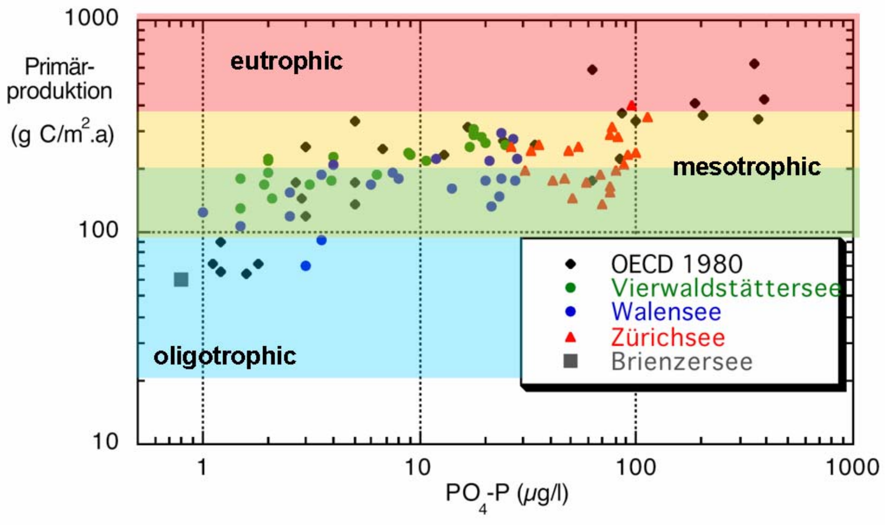

Figure 3

Major Findings: Nutrient limiting factor and primary production	
1.	**Relying on the nutrient concentration presented by the EIAR (2005), we estimate that phosphorus may be the limiting factor for the reservoir's productivity.**
2.	**However, the present phosphorus concentrations are high enough to support a high productivity level in the range of between 250 and 700 g C m^{-2} yr^{-1}.**
3.	**Using the reservoir surface area of 300 km^2, we estimate an annual carbon fixation of between 72,000 t yr^{-1} and 216,000 t C yr^{-1}.**
4.	**During organic matter decomposition within the water column or sediment, high oxygen consumption rates are expected, leading to total oxygen depletion in deep water. Therefore, anoxic conditions are anticipated a few meters below the surface down to the lake floor which can mobilize heavy metals contained in the sediment.**
5.	**Oxygen-depleted water is not suitable for fish or other organisms. Fish and their eggs will not be able to survive in the deep, stratified water of the reservoir. The absence of oxygen in deep water together with high sedimentation rates may result in the total extinction of benthic organisms in the reservoir area.**
6.	**The release from the dam of colder, anoxic water, possibly enriched with heavy metals, may have negative impacts on downstream ecology as well as on water use for domestic activities or irrigation.**

4.3.5. Greenhouse Gas Emissions

Concerning greenhouse gas emissions from the Ilisu Reservoir, in the EIAR (2005) on page 4-62, the following affirmation is made:

"The flooding of trees and vegetation will contribute to a biomass input in the reservoir. This organic biomass will eventually decompose generating greenhouse gas emissions. Because the amount of kg/ha of organic material to be flooded is relatively small in semi-arid areas like Ilisu, CO_2 and CH_4 emissions by the reservoir itself should be small through the life cycle of the Project compared to reservoirs of the same size in tropical areas."

This assumption is not totally correct. Besides flooding of existing trees and vegetation, the reservoir will support high primary production and therefore a large mass of degradable organic matter will be produced *in-situ* annually. Part of the organic matter will be flushed out of the system and decompose within the water column, whereas another part will accumulate in the sediment of the reservoir. The onset of water column stratification, at least during the summer period, with anoxic conditions characterizing the deep waters, was also predicted above. Therefore, organic matter decomposition in the water column may produce both CO_2 as well as CH_4. Even in the absence of anoxic deep water, high sedimentation rates will result in a prevalence of anoxic conditions below the sediment-water interface, and therefore methane will be produced in the sediment. The methane may be exported either by ebullition or by diffusion. Ebullition results in direct flux of methane from the sediment to the atmosphere with limited impact of CH_4 oxidation in the water column (conversion of CH_4 to CO_2). The ebullition flux is generally related to the net CH_4 production rate in the sediment and the hydrostatic pressure, a function of water level fluctuations. As the diffusive transport is much slower than ebullition, a large proportion of the diffusive CH_4 flux exported from anoxic sediment will be oxidized by methane-oxidizing bacteria when the CH_4 reaches the oxic sediment or water column. In the case of a stratified water column, CH_4 will be stored in the anoxic layer and emitted rapidly by diffusion during the turnover period in winter. The diffusive flux component will depend on the difference in methane concentration between the water and atmosphere, and on the physical rate of exchange between the water and air.

High organic matter inflow is expected to correspond to large N and P loads characterizing the Tigris River. Unfortunately, no data on the organic matter is given by the EIAR (2005) and therefore no estimate of the incoming load from the river upstream or the fraction of organic matter accumulating into the sediment of the reservoir has been made. However, as the upstream organic matter load is expected to be high, its contribution to the total greenhouse gas flux is likely to be large, in the same order of magnitude as the gas flux resulting from *in-situ* production. Assuming that only 10% of the estimated incoming load of between 150,000 and 300,000 t yr^{-1} organic carbon will be decomposed within the water column and the sediment, between 15,000 and 30,000 t yr^{-1} of additional organic carbon will be available for CH_4 and CO_2 production.

Primary production in the Ilisu Reservoir was previously predicted to range between 240 g C m^{-2} yr^{-1} and 720 g C m^{-2} yr^{-1}. For a surface area of 300 km^2 at the Normal Water Level, the reservoir will be responsible for producing between 72,000 t yr^{-1} and 216,000 t C yr^{-1} annually. Considering that 20% of this will be removed by sedimentation and the remaining 80% may be washed out or decomposed within the water column, the organic carbon reaching the sediment of the reservoir would range between 14,000 and 43,000 t C yr^{-1} annually. Further, it can be assumed than half of the sedimentary organic carbon will be retained in the sediment and the other half will be converted by anaerobic microbial activity into CH_4 or oxidized and released as CO_2. As the percentage of CO_2 to CH_4 produced during decomposition of organic matter depends upon many unknown parameters (the oxidation rates, the time and extent of oxygen-free conditions in the water column and below the sediment-water interface or the diffusive fluxes from the sediment), our evaluation is limited to an annual amount of total organic carbon ready to be converted into CH_4 and CO_2. This value varies between 7,000 t C yr^{-1} and 22,000 t C yr^{-1}. If all this organic carbon is converted only into CO_2, with a 1:1 ratio, the annual emission will range between 7,000 and 22,000 t CO_2 yr^{-1}. Please note that this estimate represents a lower limit, as no carbon resulting from decomposition of organic matter in the water column, no upstream load nor the existing biomass flooded by the reservoir was considered. This simple scenario demonstrates that productivity in the Ilisu Reservoir may be responsible for a large annual production of readily degradable biomass.

The EIAR (2005) estimated a total emission of CO_2 equivalent gases in the order of 22 t/TWh (1TWh = 10^3 GWh) for the first 10 years after reservoir impoundment and decreasing to 5 t/TWh afterwards. With an energy production of 3,833 GWh (page 2-3), the predicted emissions would reach:

$$(3{,}833 \text{ GWh x } 22 \text{ t } CO_2)/10^3 \text{ GWh} = 84 \text{ t } CO_2 \text{ yr}^{-1}$$

Compared to our estimates, the greenhouse gas emissions predicted by the EIAR (2005) are about three orders of magnitude lower.

Major Findings: Nutrient limiting factor and primary production	
1.	**Relying on the nutrient concentration presented by the EIAR (2005), we estimate that phosphorus may be the limiting factor for reservoir productivity.**
2.	**However, the present phosphorus concentrations are high enough to support a high productivity level of between 250 and 700 g C m^{-2} yr^{-1}.**
3.	**Using the reservoir surface area of 300 km^2, we estimate an annual *in-situ* carbon fixation of between 70,000 t yr^{-1} and 200,000 t C yr^{-1}.**
4.	**The organic carbon available for CO_2 and CH_4 production in the sediment of the Ilisu Reservoir may range between 7,000 and 22,000 t C yr^{-1}. These values represent a lower estimate and do not include the additional carbon transported into the reservoir from the river upstream.**
5.	**Compared to the EIAR (2005) prediction of CO_2 emissions, the greenhouse gas *in-situ* produced in the Ilisu Reservoir may be three orders of magnitude higher.**

4.4. Water Balance

4.4.1. Precipitation

The following data are presented by the EIAR (2005):

- Average annual precipitation in the area of the reservoir: 814 mm (814 mm mm^{-2} yr^{-1})
- Reservoir area: 100 ÷ 313x10^6 m^2
- Subcatchment area within the reservoir: catchment area at Ilisu (35,517 km^2) minus catchment area at Rezuk (34,623 km^2) equals 894x10^6 m^2

The annual volume gain due to precipitation only on the reservoir surface can be calculated as:

$$(100 \div 313)\text{x}10^6\ m^2 \text{ x } 0.814\ m\ yr^{-1} = 81 \div 255\ m^3\ yr^{-1}$$

The annual volume gain due to precipitation from the subcatchment within the reservoir can be estimated as:

$$894\text{x}10^6\ m^2 \text{ x } 0.814\ m\ yr^{-1} = 728\text{x}10^6\ m^3\ yr^{-1}$$

Subtracting from this volume the water directly gained on the surface area, the calculations lead to 646.3 and 472.9x10^6 m^3 yr^{-1}. Considering that only 15% of this actually reaches the reservoir, as assumed by EIAR (2005) for the water used in irrigation scheme, the real contribution of precipitation from the subcatchment within the reservoir may only be between 97 and 71x10^6 m^3 yr^{-1}.

According to this, the total annual precipitation will range between 178x10^6 m^3 yr^{-1} (calculated as 81+97=178) and 326x10^6 m^3 yr^{-1} (calculated as 255+71).

Therefore, influenced by the reservoir area, the volume of water gained due to precipitation will vary between a minimum of 0.18 km^3 yr^{-1} and an upper limit of 0.33 km^3 yr^{-1}. This represents between 1.7 and 3.2% of the reservoir volume of 10.41 km^3 or with 1 to 2% of the river inflow of 15.45 km^3 yr^{-1}.

4.4.2. Evaporation

- The average annual evaporation rate was described as high as 1,695 mm (mm mm^2 yr^{-1})
- The reservoir area will fluctuate between 100 and 313x10^6 m^2

Therefore, the water lost annually due to evaporation can be calculated as:

$$(100 \div 313)\text{x}10^6\ m^2 \text{ x } 1.695\ m\ yr^{-1} = (169.5 \div 530.5)\text{x}10^6\ m^3\ yr^{-1}$$

According to my calculations, the annual volume lost through evaporation will vary between 0.17 km^3 yr^{-1} and 0.53 km^3 yr^{-1}. This represents a loss of 1.6 to 5% of the reservoir volume, or between 1 and 3.5% of the river inflow.

In Enclosures, on page 20, the EIAR (2005) reported a total volume lost annually due to evaporation of between 0.35 and 0.4 km^3 yr^{-1} representing 2.2 to 2.5% of the annual flow of $15{,}849 \times 10^6$ m^3 yr^{-1}. However, their predicted evaporation is in the same range with our rough estimate and therefore it seems to be acceptable.

The volume lost annually through evaporation of 0.17÷0.53 km^3 yr^{-1} is more or less compensated for by the volume of water gain from precipitation of 0.18÷0.33 km^3 yr^{-1} and therefore, the influence on the overall water balance will be minor.

Major Findings: Precipitation and evaporation	
1.	**Using a precipitation value of 814 mm and evaporation of 1,695 mm, and a reservoir surface area fluctuation between 100 and 313 km^2, the annual volume gain through precipitation will vary between 0.18 and 0.33 km^3 yr^{-1} whereas between 0.17 and 0.53 km^3 yr^{-1} will be lost annually through evaporation.**
2.	**The volume of water lost annually through evaporation (up to 3% of the river inflow) is compensated for by the annual precipitation, and therefore the influence on the total water balance can be considered negligible.**
3.	**Comparable precipitation and evaporation volumes were calculated by the EIAR (2005), and therefore their estimates seem to be correct.**

4.4.3. Irrigation

Although the impact of evaporation/precipitation on the reservoir water balance can be considered negligible, the water abstraction due to irrigation demand may play an important role in the total balance.

In the EIAR (2005), the water demand for irrigation projects is quite well done (Enclosures, page 18). The total water required for agriculture from April to October, with two categories of project (in operation, under construction, or in planning) was considered by the EIAR (2005) to amount to a total of 2.2 km^3 yr^{-1} annually: 1.2 km^3 yr^{-1} for Category 1 projects and an additional 1 km^3 yr^{-1} if Category 2 projects are considered.

With the assumption that 15% of this water will return to the river, the net water abstraction for irrigation will reach only 1.9 km^3. This value seems to be correct, corresponding to a present demand of about 6.5% of the inflow (1 km^3 yr^{-1}) and reaching 12% in the future.

Major Findings: Irrigation	
1.	**No re-evaluation or additional calculations of water abstraction for irrigation purposes beyond the reported value have been performed.**
2.	**With a present requirement of 1.2 km^3 yr^{-1}, the irrigation scheme will use more than 6% of the river inflow increasing to 12% in the future.**
3.	**This will lead to increased N and P loads from fertilizers and pesticides. As part of the water used for the irrigation scheme is anticipated by the EIAR (2005) to return to the reservoir, an increase in reservoir salt content is therefore expected. Evaporation may also contribute, to a lesser extent, to increased reservoir salt content.**

4.4.4. Filling the Reservoir

The hydrology of the reservoir is complex and generally well described in different chapters of the EIAR (2005). We focus here only on the discharge flow and the time span for filling the reservoir.

In order to secure a minimum outflow during impounding, the EIAR (2005) proposes the following monthly discharge rules:

- From April through October: Q_{min}=60 m^3 s^{-1} +0.5x(Q_{inflow}-60)m^3 s^{-1}
- From November through March: Q_{min}=100 m^3 s^{-1}

Critical questions regarding the hydrological regime include:

(i) How often do very dry years occur, and what are their discharge characteristics?
(ii) What is the probability that the reservoir cannot provide the minimum downstream flow?
(iii) How do irrigation needs affect the water balance?
(iv) What is the time required to fill the reservoir, considering the downstream water release rules defined above?

In Enclosures on page 26, Table 14 lists the monthly inflows for dry, average and wet conditions. We use this table (considering that the data presented are in $m^3 s^{-1}$ as in Table 13 on page 25, and not in Mm^3 which will imply overall 60% lower values) to calculate the monthly outflow (Q_{out}) according to the above formulas for three possible situations: dry, average and wet years (see Table 1). Converted to km^3 per month, the difference between the inflow (Q_{in}) and the outflow (Q_{out}) represents the monthly water volume available for storage (Table 2). In the EIAR (2005) on page 18 (Enclosures), Table 7 shows the monthly irrigation demand between April and October considering again two project categories. We consider only Category 1, as the Ilisu Dam construction and the reservoir impounding will not take that long before the Category 2 projects (in reconnaissance, planning or in program) will be implemented.

Table 2 shows the present irrigation demand without considering the return of 15% of the water used for irrigation, as the period required may be larger that the impounding period. Therefore, securing a minimum downstream flow between 5 and 7 $km^3 yr^{-1}$, a water volume of 6 $km^3 yr^{-1}$ up to 11 $km^3 yr^{-1}$ can be stored annually without considering the irrigation demand. With the annual irrigation demand up to 1.2 $km^3 yr^{-1}$, the annual storage may range between 5 and 10 $km^3 yr^{-1}$ (Table 3).

$$Q_{out\_April\text{-}October}=60m^3/s-0.5*(Qin-60m^3/s)$$

$$Q_{out\_Nov.\text{-}March}=60m^3/s-0.5*(Qin-60m^3/s)$$

	Q_{in} (m^3/s)			Q_{out} (m^3/s)				
Months	**Dry**	**Aver.**	**Wet**	**Dry**	**Aver.**	**Wet**	**days**	**sec**
April	1002.88	1337.17	1604.61	531.44	698.59	832.31	30	2592000
May	797.69	1063.58	1276.30	428.85	561.79	668.15	31	2678400
June	341.93	455.91	547.09	200.97	257.96	303.55	30	2592000
July	141.94	189.26	227.11	100.97	124.63	143.56	31	2678400
August	85.27	113.70	136.44	72.64	86.85	98.22	31	2678400
September	75.87	101.17	121.40	67.94	80.59	90.70	30	2592000
October	103.87	138.49	166.19	81.94	99.25	113.10	31	2678400
November	171.95	229.27	275.13	100	100	100	30	2592000
December	272.15	362.87	435.44	100	100	100	31	2678400
January	260.01	346.68	416.02	100	100	100	31	2678400
February	397.11	529.48	635.38	100	100	100	28	2419200
March	677.25	903.00	1083.60	100	100	100	31	2678400

Table 1

	Q_{in} (km^3/month)			Q_{out} (km^3/month)			Q_{in}-Q_{out} (km^3/month)			**Irrigation**
Months	**Dry**	**Aver.**	**Wet**	**Dry**	**Aver.**	**Wet**	**Dry**	**Aver.**	**Wet**	**km^3/month**
April	2.599	3.466	4.159	1.377	1.811	2.157	1.222	1.655	2.002	0.000
May	2.137	2.849	3.418	1.149	1.505	1.790	0.988	1.344	1.629	0.083
June	0.886	1.182	1.418	0.521	0.669	0.787	0.365	0.513	0.631	0.277
July	0.380	0.507	0.608	0.270	0.334	0.384	0.110	0.173	0.224	0.324
August	0.228	0.305	0.365	0.195	0.233	0.263	0.034	0.072	0.102	0.283
September	0.197	0.262	0.315	0.176	0.209	0.235	0.021	0.053	0.080	0.175
October	0.278	0.371	0.445	0.219	0.266	0.303	0.059	0.105	0.142	0.040
November	0.446	0.594	0.713	0.259	0.259	0.259	0.186	0.335	0.454	0.000
December	0.729	0.972	1.166	0.268	0.268	0.268	0.461	0.704	0.898	0.000
January	0.696	0.929	1.114	0.268	0.268	0.268	0.429	0.661	0.846	0.000
February	0.961	1.281	1.537	0.242	0.242	0.242	0.719	1.039	1.295	0.000
March	1.814	2.419	2.902	0.268	0.268	0.268	1.546	2.151	2.634	0.000
Sum: (km^3 yr^{-1})	11.351	15.135	18.162	5.212	6.330	7.224	**6.139**	**8.805**	**10.938**	1.182

Table 2

	Dry	Average	Wet
Annual volume stored without irrigation (km^3/yr)	**6.139**	**8.805**	**10.938**
Annual volume stored with irrigation (km^3/yr)	**4.957**	**7.623**	**9.756**

	Time period (months) to fill the reservoir volume of 10.41 km^3	
	without irrigation	**with irrigation**
Dry	20	25
Average	14	16
Wet	11	13

Table 3

According to our calculations, without considering the water abstraction for irrigation, the time required to fill the reservoir may vary between 11 and 20 months for wet and dry years, respectively. Including the water abstraction for irrigation, the period may be extended to 13 and 25 months, respectively (Table 3).

It is known that the dam operation policy is to reduce the impounding phase as much as possible in order to produce electric power sooner. Therefore the EIAR (2005) simulated the reservoir impoundment, choosing 4 arbitrary starting dates: March 1st, June 1st, September 1st and December 1st. We summarize their results concerning the time required to fill the reservoir storage capacity in Table 4. According to EIAR (2005), starting March 1st and considering a wet year, the minimum necessary time to reach the Normal Water Level of 525 m (a.s.l.) corresponding to a storage volume of 10.41 km^3 was only 2 months (Enclosures, page 27, Table 4). This is obviously wrong, but before explaining why, the confusion between the terminology and data presented here should be pointed out. For example, in Enclosures on page 23, Table 11 gives the relationship between surface, volume and elevation. The total storage volume of 10.41 km^3 corresponds to a surface area of 313 km^2 at Normal Water Level of 525 m a.s.l. (Table 10, page 22). Page 2-29 describes the reservoir surface area of 300 km^2 at Normal Water Level (525) and 313 km^2 at Maximum Water Level of 526.8 m. The same page relates the Normal Water Level to the "live storage" capacity of 7,460 km^3. It would have been very helpful if the data and/or terminology had been more consistent.

Returning to the impounding time and starting on March 1st, even for a wet year when March and April may have the highest flow, the discharge represents together a volume of only 7.06 km^3 or 68% of the total reservoir. With an outflow calculated as 2.4 km^3, the water stored in the reservoir during March and April would reach a maximum of 4.6 km3 or about 45% of the storage capacity. Therefore, the reservoir cannot be filled in only 2 months.

Starting date		Dry	Average	Wet
		[months]		
March 1st	No irrigation	24	10	2
	Irrigation	25	11	2
June 1st	No irrigation	23	10	9
	Irrigation	33	10	9
September 1st	No irrigation	20	7	6
	Irrigation	20	7	6
December 1st	No irrigation	16	4	4
	Irrigation	27	4	4

Table 4. EIAR (2005) predictions for the impounding time (months)

We run a similar simulation using the same arbitrary starting dates. The results are summarized in Table 5 and listed in detail in the Appendix (Tables 6 to 13). The comparison between the EIAR (2005) estimates and our calculated impounding period shows agreement for a dry year. In general, values that are lower by a factor of two were calculated by EIAR (2005) for an average flow year, and more than a factor of three for a wet year could be found between the EIAR (2005) values compared to our simulated data.

Starting date		Dry	Average	Wet
		[months]		
March 1st	No irrigation	18	13	12
	Irrigation	24	13	12
June 1st	No irrigation	23	19	12
	Irrigation	33	22	19
September 1st	No irrigation	20	17	10
	Irrigation	28	18	15
December 1st	No irrigation	17	14	11
	Irrigation	25	15	13

Table 5. Our simple calculations for the impounding time (months)

Major Findings: Impounding time	
1.	**For average flow years and wet years, the simulation of the impounding period performed by the EIAR (2005) seems to be in general a factor of 2 (for average discharge years) and 3 (for wet years), respectively, lower than our estimated periods.**
2.	**As the impounding time is an important parameter for the hydroelectric company controlling the starting of power production, regulating the downstream discharge and influencing the reservoir water quality, a better analysis of this parameter may be essential.**

5. Summary: Overview of major findings (see boxes above)

5.1 Seismicity

1. Reservoir-induced seismicity is expected to appear after a few years following impounding.
2. For magnitudes below 6 on the Richter scale, an induced seismic activity may not represent an issue for the project.

5.2 Sedimentation

1. A sediment yield of 3.3×10^6 m^3 yr^{-1} was calculated by the EIAR (2005) from the catchment area based on an empirical formula.
2. An inflow sediment load of 2.5×10^6 m^3 yr^{-1} was also predicted by the EIAR (2005) based on model simulation. This inflow load is actually lower than the total reservoir accumulation.
3. A load of between 15 and 30×10^6 t m^3 yr^{-1}, one order of magnitude higher than previous values was later reported by the EIAR (2005) to represent the sediment load of the river at the dam site. This load is also described in the old EIAR (2001).
4. No dataset on suspended solids concentration is available to estimate which value should be considered closer to the real situation.
5. Based on residence time we were able to predict a retention capacity of up to 96% of the incoming load. Using an average sediment load of 22.5×10^6 m^3 yr^{-1} annually, up to 21x106 m^3 yr^{-1} can be accumulated in the Ilisu Reservoir.
6. No assessment of the impacts from such sedimentation was done by the EIAR (2005) for the reservoir itself, nor for the river downstream.
7. No prediction for an important physical parameter – reservoir lifetime – was done by the EIAR (2005). According to our calculations, the reservoir lifetime will vary between 100 and 400 years.

5.3 Thermal stratification

1. The onset of thermal stratification is mentioned in the EIAR (2005) but no estimate of the extent of this parameter was made.
2. Using an empirical formula based on the water residence time, we were able to predict, with large uncertainty, an upper limit temperature difference of 19°C between the surface and 30 m depth during the summer period.
3. It seems probable that the stratification will be disrupted during annual floods, but a minimum stratification will be maintained for the reservoir area in front of the dam. During the winter, a mixing process between surface and deep water is expected

due to overturn, supplying oxygen to the hypolimnion and increasing the surface nutrient pool.

5.4 Nutrients

1. High nutrient concentrations in the entire stretch of river and at the dam site are reported by the EIAR (2005) but no quantification of the impact of high nutrient loading on water quality and internal biogeochemical processes (such as primary production, oxygen depletion, nutrient cycle, greenhouse gas emissions or subsequent downstream-related impacts) has been done.
2. Using the EIAR (2005) stated concentrations of 3.5 mg N l^{-1} and 0.24 mg P l^{-1}, we were able to calculate an annual nutrient load of 54,000 t N yr^{-1} and 3,700 t P yr^{-1} respectively. We also predict an annual incoming load between 150,000 and 300,000 t yr^{-1} of organic carbon.
3. From a residence time of 0.7 years, we predict an annual increase in reservoir nutrient concentrations up to 5%. This implies that the availability of nutrients in the reservoir will be mainly dependent on the incoming loads and to a lesser extent on internal processes. However, as predicted by the EIAR (2005), to decrease during the coming period due to implementation of waste treatment plants, the nutrient loads will still go high up into the eutrophic level.

5.5 Nutrient limiting factor and primary production

1. Relying on the nutrient concentration presented by the EIAR (2005), we estimate that phosphorus may be the limiting factor for the reservoir's productivity.
2. However, the present phosphorus concentrations are high enough to support a high productivity level in the range of between 250 and 700 g C m^{-2} yr^{-1}.
3. Using the reservoir surface area of 300 km^2, we estimate an annual carbon fixation of between 72,000 t yr^{-1} and 216,000 t C yr^{-1}.
4. During organic matter decomposition within the water column or sediment, high oxygen consumption rates are expected, leading to total oxygen depletion in deep water. Therefore, anoxic conditions are anticipated a few meters below the surface down to the lake floor which can mobilize heavy metals contained in the sediment.
5. Oxygen-depleted water is not suitable for fish or other organisms. Fish and their eggs will not be able to survive in the deep, stratified water of the reservoir. The absence of oxygen in deep water together with high sedimentation rates may result in the total extinction of benthic organisms in the reservoir area.

5.6 Precipitation and evaporation

1. Using a precipitation value of 814 mm and evaporation of 1,695 mm, and a reservoir surface area fluctuation between 100 and 313 km^2, the annual volume

gain through precipitation will vary between 0.18 and 0.33 $km^3\ yr^{-1}$ whereas between 0.17 and 0.53 $km^3\ yr^{-1}$ will be lost annually through evaporation.

2. The volume of water lost annually through evaporation (up to 3% of the river inflow) is compensated for by the annual precipitation, and therefore the influence on the total water balance can be considered negligible.
3. Comparable precipitation and evaporation volumes were calculated by the EIAR (2005), and therefore their estimates seem to be correct.

5.7 Irrigation

1. No re-evaluation or additional calculations of water abstraction for irrigation purposes beyond the reported value have been performed.
2. With a present requirement of 1.2 $km^3\ yr^{-1}$, the irrigation scheme will use more than 6% of the river inflow increasing to 12% in the future.
3. This will lead to increased N and P loads from fertilizers and pesticides. As part of the water used for the irrigation scheme is anticipated by the EIAR (2005) to return to the reservoir, an increase in reservoir salt content is therefore expected. Evaporation may also contribute, to a lesser extent, to increased reservoir salt content.

5.8 Impounding time

1. For average flow years and wet years, the simulation of the impounding period performed by the EIAR (2005) seems to be in general a factor of 2 (for average discharge years) and 3 (for wet years), respectively, lower than our estimated periods.
2. As the impounding time is an important parameter for the hydroelectric company controlling the starting of power production, regulating the downstream discharge and influencing the reservoir water quality, a better analysis of this parameter may be essential.

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Appendix

Simulation without irrigation:

	1st March	Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. without irrigation		
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet
1	March	1.814	2.419	2.902	0.268	0.268	0.268	1.546	2.151	2.634
2	April	2.599	3.466	4.159	1.377	1.811	2.157	2.768	3.806	4.636
3	May	2.137	2.849	3.418	1.149	1.505	1.790	3.756	5.150	6.265
4	June	0.886	1.182	1.418	0.521	0.669	0.787	4.121	5.663	6.896
5	July	0.380	0.507	0.608	0.270	0.334	0.384	4.231	5.836	7.120
6	August	0.228	0.305	0.365	0.195	0.233	0.263	4.265	5.908	7.223
7	September	0.197	0.262	0.315	0.176	0.209	0.235	4.286	5.961	7.302
8	October	0.278	0.371	0.445	0.219	0.266	0.303	4.344	6.067	7.444
9	November	0.446	0.594	0.713	0.259	0.259	0.259	4.531	6.402	7.898
10	December	0.729	0.972	1.166	0.268	0.268	0.268	4.992	7.106	8.797
11	January	0.696	0.929	1.114	0.268	0.268	0.268	5.420	7.766	9.643
12	February	0.961	1.281	1.537	0.242	0.242	0.242	6.139	8.805	10.938
13	March	1.814	2.419	2.902	0.268	0.268	0.268	7.685	10.956	13.573
14	April	2.599	3.466	4.159	1.377	1.811	2.157	8.907	12.611	15.575
15	May	2.137	2.849	3.418	1.149	1.505	1.790	9.895	13.955	17.204
16	June	0.886	1.182	1.418	0.521	0.669	0.787	10.261	14.468	17.835
17	July	0.380	0.507	0.608	0.270	0.334	0.384	10.370	14.642	18.059
18	August	0.228	0.305	0.365	0.195	0.233	0.263	10.404	14.713	18.161
19	September	0.197	0.262	0.315	0.176	0.209	0.235	10.425	14.767	18.241
20	October	0.278	0.371	0.445	0.219	0.266	0.303	10.483	14.872	18.383

Table 6

	1st June	Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain without irrigation		
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet
1	June	0.886	1.182	1.418	0.521	0.669	0.787	0.365	0.513	0.631
2	July	0.380	0.507	0.608	0.270	0.334	0.384	0.475	0.686	0.855
3	August	0.228	0.305	0.365	0.195	0.233	0.263	0.509	0.758	0.957
4	September	0.197	0.262	0.315	0.176	0.209	0.235	0.530	0.811	1.037
5	October	0.278	0.371	0.445	0.219	0.266	0.303	0.588	0.917	1.179
6	November	0.446	0.594	0.713	0.259	0.259	0.259	0.775	1.252	1.633
7	December	0.729	0.972	1.166	0.268	0.268	0.268	1.236	1.956	2.532
8	January	0.696	0.929	1.114	0.268	0.268	0.268	1.664	2.616	3.378
9	February	0.961	1.281	1.537	0.242	0.242	0.242	2.383	3.655	4.673
10	March	1.814	2.419	2.902	0.268	0.268	0.268	3.929	5.806	7.308
11	April	2.599	3.466	4.159	1.377	1.811	2.157	5.151	7.461	9.310
12	May	2.137	2.849	3.418	1.149	1.505	1.790	6.139	8.805	10.938
13	June	0.886	1.182	1.418	0.521	0.669	0.787	6.505	9.318	11.570
14	July	0.380	0.507	0.608	0.270	0.334	0.384	6.614	9.492	11.793
15	August	0.228	0.305	0.365	0.195	0.233	0.263	6.648	9.564	11.896
16	September	0.197	0.262	0.315	0.176	0.209	0.235	6.669	9.617	11.975
17	October	0.278	0.371	0.445	0.219	0.266	0.303	6.727	9.722	12.118
18	October	0.278	0.371	0.445	0.219	0.266	0.303	6.786	9.827	12.260
19	November	0.446	0.594	0.713	0.259	0.259	0.259	6.973	10.162	12.714
20	December	0.729	0.972	1.166	0.268	0.268	0.268	7.434	10.866	13.612
21	January	0.696	0.929	1.114	0.268	0.268	0.268	7.862	11.527	14.459
22	February	0.961	1.281	1.537	0.242	0.242	0.242	8.581	12.566	15.754
23	March	1.814	2.419	2.902	0.268	0.268	0.268	10.127	14.717	18.388
24	April	2.599	3.466	4.159	1.377	1.811	2.157	11.349	16.372	20.390

Table 7

1st September		Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain without irrigation		
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet
1	September	0.197	0.262	0.315	0.176	0.209	0.235	0.021	0.053	0.080
2	October	0.278	0.371	0.445	0.219	0.266	0.303	0.079	0.158	0.222
3	November	0.446	0.594	0.713	0.259	0.259	0.259	0.266	0.494	0.676
4	December	0.729	0.972	1.166	0.268	0.268	0.268	0.727	1.198	1.574
5	January	0.696	0.929	1.114	0.268	0.268	0.268	1.155	1.858	2.421
6	February	0.961	1.281	1.537	0.242	0.242	0.242	1.874	2.897	3.716
7	March	1.814	2.419	2.902	0.268	0.268	0.268	3.420	5.048	6.350
8	April	2.599	3.466	4.159	1.377	1.811	2.157	4.642	6.703	8.352
9	May	2.137	2.849	3.418	1.149	1.505	1.790	5.630	8.047	9.981
10	June	0.886	1.182	1.418	0.521	0.669	0.787	5.996	8.560	10.612
11	July	0.380	0.507	0.608	0.270	0.334	0.384	6.105	8.733	10.836
12	August	0.228	0.305	0.365	0.195	0.233	0.263	6.139	8.805	10.938
13	September	0.197	0.262	0.315	0.176	0.209	0.235	6.160	8.859	11.018
14	October	0.278	0.371	0.445	0.219	0.266	0.303	6.219	8.964	11.160
15	November	0.446	0.594	0.713	0.259	0.259	0.259	6.405	9.299	11.614
16	December	0.729	0.972	1.166	0.268	0.268	0.268	6.866	10.003	12.513
17	January	0.696	0.929	1.114	0.268	0.268	0.268	7.295	10.664	13.359
18	February	0.961	1.281	1.537	0.242	0.242	0.242	8.013	11.703	14.654
19	March	1.814	2.419	2.902	0.268	0.268	0.268	9.560	13.853	17.289
20	April	2.599	3.466	4.159	1.377	1.811	2.157	10.782	15.509	19.290

Table 8

1st December		Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain without irrigation		
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet
1	December	0.729	0.972	1.166	0.268	0.268	0.268	0.461	0.704	0.898
2	January	0.696	0.929	1.114	0.268	0.268	0.268	0.890	1.365	1.745
3	February	0.961	1.281	1.537	0.242	0.242	0.242	1.608	2.404	3.040
4	March	1.814	2.419	2.902	0.268	0.268	0.268	3.155	4.555	5.675
5	April	2.599	3.466	4.159	1.377	1.811	2.157	4.377	6.210	7.676
6	May	2.137	2.849	3.418	1.149	1.505	1.790	5.364	7.554	9.305
7	June	0.886	1.182	1.418	0.521	0.669	0.787	5.730	8.067	9.936
8	July	0.380	0.507	0.608	0.270	0.334	0.384	5.840	8.240	10.160
9	August	0.228	0.305	0.365	0.195	0.233	0.263	5.873	8.312	10.263
10	September	0.197	0.262	0.315	0.176	0.209	0.235	5.894	8.365	10.342
11	October	0.278	0.371	0.445	0.219	0.266	0.303	5.953	8.470	10.484
12	November	0.446	0.594	0.713	0.259	0.259	0.259	6.139	8.805	10.938
13	December	0.729	0.972	1.166	0.268	0.268	0.268	6.600	9.509	11.837
14	January	0.696	0.929	1.114	0.268	0.268	0.268	7.029	10.170	12.683
15	February	0.961	1.281	1.537	0.242	0.242	0.242	7.748	11.209	13.978
16	March	1.814	2.419	2.902	0.268	0.268	0.268	9.294	13.360	16.613
17	April	2.599	3.466	4.159	1.377	1.811	2.157	10.516	15.015	18.615
18	May	2.137	2.849	3.418	1.149	1.505	1.790	11.504	16.359	20.244

Table 9

Simulation including irrigation:

	1st March	Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain with irrigation			Irrigation
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet	km^3/month
1	March	1.814	2.419	2.902	0.268	0.268	0.268	1.546	2.151	2.634	0.000
2	April	2.599	3.466	4.159	1.377	1.811	2.157	2.768	3.806	4.636	0.000
3	May	2.137	2.849	3.418	1.149	1.505	1.790	3.673	5.067	6.182	0.083
4	June	0.886	1.182	1.418	0.521	0.669	0.787	3.761	5.303	6.536	0.277
5	July	0.380	0.507	0.608	0.270	0.334	0.384	3.547	5.152	6.436	0.324
6	August	0.228	0.305	0.365	0.195	0.233	0.263	3.298	4.941	6.256	0.283
7	September	0.197	0.262	0.315	0.176	0.209	0.235	3.144	4.819	6.160	0.175
8	October	0.278	0.371	0.445	0.219	0.266	0.303	3.162	4.885	6.262	0.040
9	November	0.446	0.594	0.713	0.259	0.259	0.259	3.349	5.220	6.716	0.000
10	December	0.729	0.972	1.166	0.268	0.268	0.268	3.810	5.924	7.615	0.000
11	January	0.696	0.929	1.114	0.268	0.268	0.268	4.238	6.584	8.461	0.000
12	February	0.961	1.281	1.537	0.242	0.242	0.242	4.957	7.623	9.756	0.000
13	March	1.814	2.419	2.902	0.268	0.268	0.268	6.503	9.774	12.391	0.000
14	April	2.599	3.466	4.159	1.377	1.811	2.157	7.725	11.429	14.393	0.000
15	May	2.137	2.849	3.418	1.149	1.505	1.790	8.630	12.690	15.939	0.083
16	June	0.886	1.182	1.418	0.521	0.669	0.787	8.719	12.926	16.293	0.277
17	July	0.380	0.507	0.608	0.270	0.334	0.384	8.504	12.776	16.193	0.324
18	August	0.228	0.305	0.365	0.195	0.233	0.263	8.255	12.564	16.012	0.283
19	September	0.197	0.262	0.315	0.176	0.209	0.235	8.101	12.443	15.917	0.175
20	October	0.278	0.371	0.445	0.219	0.266	0.303	8.119	12.508	16.019	0.040
21	November	0.446	0.594	0.713	0.259	0.259	0.259	8.306	12.843	16.473	0.000
22	December	0.729	0.972	1.166	0.268	0.268	0.268	8.767	13.547	17.371	0.000
23	January	0.696	0.929	1.114	0.268	0.268	0.268	9.196	14.208	18.218	0.000
24	February	0.961	1.281	1.537	0.242	0.242	0.242	9.914	15.247	19.513	0.000
25	March	1.814	2.419	2.902	0.268	0.268	0.268	11.460	17.398	22.147	0.000

Table 10

	1st June	Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain with irrigation			Irrigation
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet	km^3/month
1	June	0.886	1.182	1.418	0.521	0.669	0.787	0.088	0.236	0.354	0.277
2	July	0.380	0.507	0.608	0.270	0.334	0.384	-0.126	0.085	0.254	0.324
3	August	0.228	0.305	0.365	0.195	0.233	0.263	-0.375	-0.126	0.073	0.283
4	September	0.197	0.262	0.315	0.176	0.209	0.235	-0.529	-0.248	-0.022	0.175
5	October	0.278	0.371	0.445	0.219	0.266	0.303	-0.511	-0.182	0.080	0.040
6	November	0.446	0.594	0.713	0.259	0.259	0.259	-0.324	0.153	0.534	0.000
7	December	0.729	0.972	1.166	0.268	0.268	0.268	0.137	0.857	1.433	0.000
8	January	0.696	0.929	1.114	0.268	0.268	0.268	0.565	1.517	2.279	0.000
9	February	0.961	1.281	1.537	0.242	0.242	0.242	1.284	2.556	3.574	0.000
10	March	1.814	2.419	2.902	0.268	0.268	0.268	2.830	4.707	6.209	0.000
11	April	2.599	3.466	4.159	1.377	1.811	2.157	4.052	6.362	8.211	0.000
12	May	2.137	2.849	3.418	1.149	1.505	1.790	4.957	7.623	9.756	0.083
13	June	0.886	1.182	1.418	0.521	0.669	0.787	5.046	7.859	10.111	0.277
14	July	0.380	0.507	0.608	0.270	0.334	0.384	4.831	7.709	10.010	0.324
15	August	0.228	0.305	0.365	0.195	0.233	0.263	4.582	7.498	9.830	0.283
16	September	0.197	0.262	0.315	0.176	0.209	0.235	4.428	7.376	9.734	0.175
17	October	0.278	0.371	0.445	0.219	0.266	0.303	4.446	7.441	9.837	0.040
19	November	0.446	0.594	0.713	0.259	0.259	0.259	4.633	7.776	10.291	0.000
20	December	0.729	0.972	1.166	0.268	0.268	0.268	5.094	8.480	11.189	0.000
21	January	0.696	0.929	1.114	0.268	0.268	0.268	5.523	9.141	12.035	0.000
22	February	0.961	1.281	1.537	0.242	0.242	0.242	6.241	10.180	13.331	0.000
23	March	1.814	2.419	2.902	0.268	0.268	0.268	7.787	12.331	15.965	0.000
24	April	2.599	3.466	4.159	1.377	1.811	2.157	9.009	13.986	17.967	0.000
25	May	2.137	2.849	3.418	1.149	1.505	1.790	9.914	15.247	19.513	0.083
26	June	0.886	1.182	1.418	0.521	0.669	0.787	10.003	15.483	19.867	0.277
27	July	0.380	0.507	0.608	0.270	0.334	0.384	9.788	15.332	19.767	0.324
28	August	0.228	0.305	0.365	0.195	0.233	0.263	9.539	15.121	19.586	0.283
29	September	0.197	0.262	0.315	0.176	0.209	0.235	9.385	14.999	19.491	0.175
30	October	0.278	0.371	0.445	0.219	0.266	0.303	9.404	15.064	19.593	0.040
31	November	0.446	0.594	0.713	0.259	0.259	0.259	9.590	15.399	20.047	0.000

32	December	0.729	0.972	1.166	0.268	0.268	0.268	10.051	16.104	20.945	0.000
33	January	0.696	0.929	1.114	0.268	0.268	0.268	10.480	16.764	21.792	0.000
34	February	0.961	1.281	1.537	0.242	0.242	0.242	11.199	17.803	23.087	0.000

Table 11

1st September		Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain with irrigation			Irrigation
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet	km^3/month
1	September	0.197	0.262	0.315	0.176	0.209	0.235	-0.154	-0.122	-0.095	0.175
2	October	0.278	0.371	0.445	0.219	0.266	0.303	-0.136	-0.057	0.007	0.040
3	November	0.446	0.594	0.713	0.259	0.259	0.259	0.051	0.279	0.461	0.000
4	December	0.729	0.972	1.166	0.268	0.268	0.268	0.512	0.983	1.359	0.000
5	January	0.696	0.929	1.114	0.268	0.268	0.268	0.940	1.643	2.206	0.000
6	February	0.961	1.281	1.537	0.242	0.242	0.242	1.659	2.682	3.501	0.000
7	March	1.814	2.419	2.902	0.268	0.268	0.268	3.205	4.833	6.135	0.000
8	April	2.599	3.466	4.159	1.377	1.811	2.157	4.427	6.488	8.137	0.000
9	May	2.137	2.849	3.418	1.149	1.505	1.790	5.332	7.749	9.683	0.083
10	June	0.886	1.182	1.418	0.521	0.669	0.787	5.421	7.985	10.037	0.277
11	July	0.380	0.507	0.608	0.270	0.334	0.384	5.206	7.834	9.937	0.324
12	August	0.228	0.305	0.365	0.195	0.233	0.263	4.957	7.623	9.756	0.283
13	September	0.197	0.262	0.315	0.176	0.209	0.235	4.803	7.502	9.661	0.175
14	October	0.278	0.371	0.445	0.219	0.266	0.303	4.822	7.567	9.763	0.040
15	November	0.446	0.594	0.713	0.259	0.259	0.259	5.008	7.902	10.217	0.000
16	December	0.729	0.972	1.166	0.268	0.268	0.268	5.469	8.606	11.116	0.000
17	January	0.696	0.929	1.114	0.268	0.268	0.268	5.898	9.267	11.962	0.000
18	February	0.961	1.281	1.537	0.242	0.242	0.242	6.616	10.306	13.257	0.000
19	March	1.814	2.419	2.902	0.268	0.268	0.268	8.163	12.456	15.892	0.000
20	April	2.599	3.466	4.159	1.377	1.811	2.157	9.385	14.112	17.893	0.000
21	May	2.137	2.849	3.418	1.149	1.505	1.790	10.289	15.373	19.439	0.083
22	June	0.886	1.182	1.418	0.521	0.669	0.787	10.378	15.609	19.794	0.277
23	July	0.380	0.507	0.608	0.270	0.334	0.384	10.164	15.458	19.693	0.324

24	August	0.228	0.305	0.365	0.195	0.233	0.263	9.914	15.247	19.513	0.283
25	September	0.197	0.262	0.315	0.176	0.209	0.235	9.760	15.125	19.417	0.175
26	October	0.278	0.371	0.445	0.219	0.266	0.303	9.779	15.190	19.520	0.040
27	November	0.446	0.594	0.713	0.259	0.259	0.259	9.965	15.525	19.973	0.000
28	December	0.729	0.972	1.166	0.268	0.268	0.268	10.426	16.229	20.872	0.000
29	January	0.696	0.929	1.114	0.268	0.268	0.268	10.855	16.890	21.718	0.000

Table 12

1st December		Q_{in} (km^3/month)			Q_{out} (km^3/month)			Vol. gain with irrigation			Irrigation
		Dry	Aver.	Wet	Dry	Aver.	Wet	Dry	Aver.	Wet	km^3/month
1	December	0.729	0.972	1.166	0.268	0.268	0.268	0.461	0.704	0.898	0.000
2	January	0.696	0.929	1.114	0.268	0.268	0.268	0.890	1.365	1.745	0.000
3	February	0.961	1.281	1.537	0.242	0.242	0.242	1.608	2.404	3.040	0.000
4	March	1.814	2.419	2.902	0.268	0.268	0.268	3.155	4.555	5.675	0.000
5	April	2.599	3.466	4.159	1.377	1.811	2.157	4.377	6.210	7.676	0.000
6	May	2.137	2.849	3.418	1.149	1.505	1.790	5.281	7.471	9.222	0.083
7	June	0.886	1.182	1.418	0.521	0.669	0.787	5.370	7.707	9.576	0.277
8	July	0.380	0.507	0.608	0.270	0.334	0.384	5.156	7.556	9.476	0.324
9	August	0.228	0.305	0.365	0.195	0.233	0.263	4.906	7.345	9.296	0.283
10	September	0.197	0.262	0.315	0.176	0.209	0.235	4.752	7.223	9.200	0.175
11	October	0.278	0.371	0.445	0.219	0.266	0.303	4.771	7.288	9.302	0.040
12	November	0.446	0.594	0.713	0.259	0.259	0.259	4.957	7.623	9.756	0.000
13	December	0.729	0.972	1.166	0.268	0.268	0.268	5.418	8.327	10.655	0.000
14	January	0.696	0.929	1.114	0.268	0.268	0.268	5.847	8.988	11.501	0.000
15	February	0.961	1.281	1.537	0.242	0.242	0.242	6.566	10.027	12.796	0.000
16	March	1.814	2.419	2.902	0.268	0.268	0.268	8.112	12.178	15.431	0.000
17	April	2.599	3.466	4.159	1.377	1.811	2.157	9.334	13.833	17.433	0.000
18	May	2.137	2.849	3.418	1.149	1.505	1.790	10.239	15.094	18.979	0.083

19	June	0.886	1.182	1.418	0.521	0.669	0.787	10.327	15.330	19.333	0.277
20	July	0.380	0.507	0.608	0.270	0.334	0.384	10.113	15.179	19.233	0.324
21	August	0.228	0.305	0.365	0.195	0.233	0.263	9.864	14.968	19.052	0.283
22	September	0.197	0.262	0.315	0.176	0.209	0.235	9.709	14.847	18.957	0.175
23	October	0.278	0.371	0.445	0.219	0.266	0.303	9.728	14.912	19.059	0.040
24	November	0.446	0.594	0.713	0.259	0.259	0.259	9.914	15.247	19.513	0.000
25	December	0.729	0.972	1.166	0.268	0.268	0.268	10.375	15.951	20.411	0.000
26	January	0.696	0.929	1.114	0.268	0.268	0.268	10.804	16.612	21.258	0.000

Table 13