Environmental changes downstream of Sardar Sarovar Dam

Report EX 2750
March 1993

HR Wallingford

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Contract

This report describes work commissioned in January 1993 by the World Bank's India Department for completion in March 1993. The HR Job Number was TQR 1428. This work was carried out by the following group of specialists coordinated by Dr P Bolton, Section Manager, Environmental Management, Overseas Development Unit. Their separate reports are reproduced as Appendices:

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Dr A S Nottage, Aquatic Biologist and Water Quality Specialist (Appendix 5)

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Summary

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The downstream impacts of Sardar Sarovar Dam are examined within the framework of the ICID Environmental Check-list of possible impacts of irrigation, drainage and flood control projects. The operational hydrology of the dam and the changes which will occur with time in the downstream releases as further irrigation is implemented upstream are considered in detail since the majority of downstream effects are determined by the hydrological regime.

Baseline studies already completed and current studies are reviewed in relation to the predicted impacts. Particular consideration is given to morphological changes, the extent of salinity intrusion at the estuary, water quality changes, and impacts on fish stocks and fisheries. The downstream reach is already heavily populated with few ecologically rich habitats. Social impacts are, therefore, likely to be more significant than ecological impacts. Study of the extent of possible adverse effects indicates that the most significant changes will occur only after a considerable period of time. In the meantime other economic and social changes may have taken place in the region. The greatest need, therefore, it to recognise and respond to changes as they occur. A set of recommendations for monitoring and mitigation are presented which are grouped according to their urgency under three headings: immediate, short-term and medium-term.

The report does not consider in detail the beneficial changes which will result from the project since these are largely in the command area and the areas supplied with drinking water. Nevertheless, most of the right bank of the downstream reach lies within the command area and will receive such benefits. An environmental assessment of the command area is being conducted separately.

The recommendations broadly support the programme of studies and actions already in progress. The conclusion is drawn that, provided that timely action is taken for mitigation and that adequate monitoring is undertaken, the effects of the anticipated impacts on the human and biological communities downstream of Sardar Sarovar can be minimised.

One issue which should be reassessed in the next ten years and regularly thereafter is whether it is feasible and appropriate to allow a minimum flow of water to be maintained in the lower Narmada. Water released through the turbines could complement downstream tributary flows to achieve these compensatory flows which would offer benefits in relation to freshwater supplies, pollution dispersal, aquatic biology and probably also human health.

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1 Introduction

1.1 The purpose

This report has been prepared to assist the Government of India (through the Narmada Control Authority, NCA) and the Government of Gujarat (through the Narmada Planning Group, NPG, and the Sardar Sarovar Narmada Nigam Ltd, SSNNL) in the preparation of documentation required by the World Bank identifying the environmental changes likely to occur downstream of Sardar Sarovar Dam. The report was prepared under a consultancy with the World Bank the terms of reference for which are given in Appendix 1.

1.2 The context

The Sardar Sarovar Dam is part of a series of projects (known as the Sardar Sarovar Projects, SSP) whereby water from the Narmada River is to be diverted for agricultural, domestic and industrial use in a wide area of Gujarat and Rajasthan as well as to generate hydropower. A detailed introduction to the SSP is given by NPG (1989) in which the projects' importance for the future economic and social development of a major part of the state of Gujarat is described. The SSP also forms a major component in the planned integrated development of the whole Narmada basin with important implications for economic and social development in the states of Madhya Pradesh, Maharastra and Rajasthan as well as Gujarat. It is, therefore, important to view the Sardar Sarovar Dam as part of a broad and ambitious plan for the future development of a large region of north-west India rather than as an isolated project.

The terms of reference specify that the consultants should address the likely environmental impacts of Sardar Sarovar Dam on the Narmada river estuary including the portion of the river from the dam site to the sea. Normally when environmental assessments are made a comprehensive view of the entire scope of possible impacts is required. This broad view is being taken with respect to Sardar Sarovar but aspects of the assessment are being addressed separately as well; notably the command area impacts and the reservoir, upstream and downstream impacts. Certain issues are not addressed in the present report but are addressed elsewhere.

In narrowing the scope of the present report there is a danger that a rather unbalanced view of the overall impact of the dam will emerge since the positive benefits of the project are only partly evident in the downstream reach. Against the negative impacts which emerge, therefore, should be set the benefits of irrigated crop production, domestic and industrial water use and hydroelectric energy production which will be seen in a wide region.

The desire to harness the waters of the Narmada River was frustrated for many years by the difficulty of reaching agreement between the basin states as to an equitable apportionment of the waters. The difficulty was resolved through the Narmada Water Disputes Tribunal (NWDT) which sat from 1969 to 1979. The Tribunal looked ahead to the complete utilisation of the waters of the basin over a period of more than 45 years. Using the Tribunal agreements it is, therefore, possible to forecast the patterns of water use in the Narmada for many years ahead. Various stages of development were envisaged by the Tribunal, as described in Appendix 3. It is important to note that the difference between the final two stages (Stage 2 and Stage 3) does not result from any change in water use at Sardar Sarovar but from an increase in consumptive use upstream. Again, it is clear that Sardar Sarovar should not be viewed as an isolated project but as an integral part of the whole development of the Narmada basin.

The current situation in which the environmental changes envisaged by the development of the entire resources of a river basin can be assessed prior to the completion of the first major dam is rare, if not unique. The opportunities it gives for long-term monitoring and mitigation are considerable. The reader should be aware, however, that the severity of some of the possible long-term impacts will seem greater than if the Sardar Sarovar Dam had been built as a single project unrelated to the broader plans for development of the basin as a whole.

1.3 The lower Narmada River

The area on which this report focuses is the river channel and estuary of the Narmada together with the, relatively narrow, strips of land on either bank which form the downstream drainage basin, see Figure 1. The total land area of this region is approximately 10% of the total drainage basin area of the Narmada River. There are two main tributaries downstream of Sardar Sarovar; the Orsang on the right bank and the Karjan on the left. There already exists a major dam on the Karjan (recently completed) from which a large portion of the land on the left bank will be irrigated. Canals from the Ukai Dam on the Tapi River (the next major river south of the Narmada) are also being built to irrigate some of the remaining lands on the left bank of the Narmada. The Orsang is less regulated than the Karjan but a number of dams have been proposed. In addition the right bank of the Narmada lies within the command area to be irrigated from the canals supplied from Sardar Sarovar.

At the head of the estuary lies the town of Bharuch (formerly Broach). This was an ancient port and commercial centre but with the ever-increasing size of cargo vessels, Bharuch's restricted access and high tidal range made it unsuitable as a modern port with the result that very little traffic has used it since the early part of this century. Commerce and industry have continued to flourish, however, partly due to the fact that the main road and rail links from Ahmedabad and Vadodara (Baroda) to Bombay cross the Narmada at Bharuch. Industrial development is expanding on both banks (at Bharuch on the right bank and Ankleshwar on the left) with fertilizer and chemical factories particularly dominant.

In addition, reserves of oil and natural gas have been found around the estuary and there is, at present, a rush of exploration and exploitation. Some of these resources will be used to fire a new thermal power station being built on the right bank of the Narmada upstream of Bharuch.

Any impact on the downstream region, which results from the Sardar Sarovar Dam should, therefore, be seen in the context of the current level of development in the region. In particular there are few areas remaining in which the natural ecology has not already been, or will soon be, modified by human activities largely unrelated to the dam, and the current and planned levels of industrial development are likely to be the dominant factors in relation to environmental change in the region.

1.4 Previous studies

Two studies commissioned by the Government of Gujarat form the primary sources for previous overviews of the downstream impacts and have been used for this report:

- MS University (1983) is widely quoted and its data and conclusions have never seriously been challenged except for the fact that the field surveys were for a rather short period (6 months).

- SSNNL (1992) provides a more detailed technical understanding of the likely hydrological changes and discusses possible impacts in relation to these.

The principal environmental changes identified by MS University with regard to the downstream region are as follows:

- impact on fisheries especially hilsa
- reduced sediment flow affecting estuarine biota (flora and fauna)
- possible effect on groundwater levels and salinity
- increased aquatic weeds and marshes around the estuary
- increased saline water ingress in the estuary
- reduced floods
- both positive and negative effects on human health

A series of mitigating measures was set out in respect of each of these.

The report by SINNL (1992) focused particularly on:

- water availability and use in the river reach
- water quality changes
- esturial changes
- fishing
- flood protection
- groundwater recharge
- recreation
- changes to the islands in the estuary
- navigation

Over the last 10 years various reports and reviews have been conducted for the World Bank, many of them considering the possible environmental impacts specifically. These reports provided a few additional insights into possible downstream impacts but have provided little or no new data and information relevant to the expected changes. Their contributions are shown below:

- World Bank (1985 a and b) contain details of the project's hydrology and the outcome of the NWDT
- Rees (1988) stresses the need for an integrated approach in understanding the nature of the likely changes
- Levenhagen (1989) raises the issue of existing water uses (industrial, domestic and cultural) and summarises available water quality data. He also provides an extensive bibliography
- Whitington (1992) is not strictly relevant to the downstream impacts
- Morse (1992) raises the issue of channel degradation downstream of the dam.

In addition to the overviews described above a number of specific studies have either been completed or are in progress in relation to particular impacts (notably hydrology, morphology, salinity, flora and fauna and fisheries). These studies are described under the relevant sections below.

2 Scoping for key issues

To ensure that no key issues have been overlooked the draft ICID check-list of environmental impacts (Mock and Bolton, 1993) has been used to scope for key issues. (The check-list is reproduced in Appendix 2). The following sections consider each item in the check-list in turn. The key issues identified below are then summarised in Section 3. Detailed technical discussion is not included in the following sections but may be found in appendices which were prepared by the specialists engaged in the consultancy.

Where items relate to impacts solely within the command area or upstream, having no relevance to impacts in the downstream reach, this is indicated and further reference should be made to reports relating to these areas.

2.1 Hydrological changes

These are the key to all other impacts in the downstream reach and are discussed in detail in Appendix 3.

2.1.1 Low flow regime

The changes to the non-monsoon flows at various stages of project development are described in Appendix 3 and shown in Figure A3.2. They may be summarised as an increase in the total discharge for the seven months November to May by $10x10^9m^3$ or more in the early years falling to a condition similar to the natural flows in Stage 2 and decreasing further by $2x10^9m^3$ or more in Stage 3. By Stage 3 zero flow is expected from the dam in 25% of the years. This scenario may, however, change with time if the value of hydro-electric power vis-a-vis other water uses increases. The following is, therefore, a worst case scenario.

To the discharges from the dam itself must be added flows from the downstream tributaries and catchment. The non-monsoon flows in the downstream tributaries are negligible in most years but as irrigation develops on both banks, the regeneration flows from irrigated land will increase providing at least $0.1x10^9m^3$ in most years.

On the basis of the above hydrological changes the downstream impacts in the non-monsoon season can be considered under two scenarios. These are summarised below with full details in the sections indicated:

a) Prior to Stage 2: Increased flows will lead to improved solute dispersion (Section 2.2.1), improved groundwater recharge (Section 2.1.5) and reduced salinity intrusion (Section 2.3.5).

b) After Stage 2: Gradually decreasing flows may lead to increased salinity intrusion (Section 2.3.5) possible pollution or eutrophication of the estuary (Sections 2.2.1 and 2.2.4) and impacts on aquatic life, especially fish (Section 2.5.2). There are no downstream dams which could be effected and no significant downstream navigation except by local boats with shallow draft used mainly for fishing.

There is a possibility of a short period of greatly reduced flows when the construction sluices of the dam are closed in April/May in either 1993 or 1994. The details given in Appendix 3 suggest that there will be no releases from the dam for a minimum of 10 days and a maximum period of 39 days. This could affect water supplies and salinity intrusion (Section 2.3.5).

2.1.2 Flood regime

The changes to monsoon flows at various stages are discussed in Appendix 3 and shown in Figure A3.1. The development of the Narmada basin and SSP will lead to a reduction in the total monsoon discharges below the dam by an amount rising from $20 \times 10^9 m^3$ in Stage 1 (delayed NSP) to $35 \times 10^9 m^3$ in Stage 3. The discharges will not be distributed evenly through the monsoon months but are likely to occur as an intense monsoon flow (albeit attenuated by at least 20%) for a reduced time period. Hence the monsoonal nature of the flows will not totally disappear.

In Stage 2 there is a likelihood of zero releases one year in four increasing to one year in three in Stage 3. However, since tributaries downstream of Sardar Sarovar will carry significant flows the lower river should receive at least $1 \times 10^9 m^3$ in most years.

The impact of these changes will be seen in reduced flood hazard (Sections 2.6.2 and 2.7.9) but progressively negative effects on aquatic biota (especially fish) (Section 2.5.2).

2.1.3 Operation of dams

Appendix 3 discusses the likely patterns of release from Sardar Sarovar in response to seasonal and daily fluctuations in energy demand. The Garudeshwar weir, when completed in 1996/97, will be capable of smoothing daily fluctuations provided its operators recognise the need for this. Seasonal fluctuations in demand, Figure A3.4, are not expected to be great but temporary loss of other generating plant on the network may force Sardar Sarovar to release high discharges for short periods rather than use the available energy evenly through the year.

There appears to be little scope for modifying Sardar Sarovar's operation to meet particular requirements in the downstream reach given the high value of the water and the need to adhere to the NWDT decisions. However maintenance of a minimum discharge to hold back salinity in critical periods and the timing of flood releases to assist fish migration may be possible.

The request to NWDT by Gujarat for a minimum release of $28.3 m^3 s^{-1}$ was rejected but may be something which could be reconsidered when the Tribunal reconvenes in 2024.

2.1.4 Fall of water table

The main groundwater effects are studied within the Command Area. Along the river, reduced flows after Stage 2 will reduce infiltration and may affect wells (Section 2.7.1) but on both banks this is likely to be more than compensated by increased infiltration from irrigation.

2.1.5 *Rise of water table*

As above, this is mainly on issue for the Command Area. Irrigation percolation water plus increased non-monsoon flows will cause groundwater levels on both banks of the river to rise up to Stage 2 and even after it (Section 2.1.4). Conjunctive use for irrigation should control excessive rise. In the coastal zone a rise in groundwater, if it occurs, may be considered desirable since NPG hopes to promote restoration of mangrove forests (Section 2.5.5).

2.2 Organic and inorganic pollution

Sources and types of pollutant entering the lower Narmada and their likely impacts are discussed in Appendix 5.

2.2.1 *Solute dispersion*

Industrialisation is likely to introduce the main pollution disposal problems of the future. The changed low flow regime (Section 2.1.1) will change concentrations of effluents discharged in the river

- reducing concentrations up to Stage 2
- increasing concentrations especially in the estuary after Stage 2.

2.2.2 *Toxic substances*

Agrochemical use will increase in the lower Narmada both in the SSP Command and Karjan Command. With current levels of use this is unlikely to have a major impact on Narmada water quality and certainly not until after Stage 2. This is particularly relevant to the Command Area.

It is possible that H_2S could be generated and released from the lower levels of SSP reservoir. However the lowest outlets at 53m aMSL (about 40m above bed) will rarely be used expect in high floods unless low flow augmentation is required after Stage 2. Prior to this a study of limnology in the reservoir should be completed.

2.2.3 *Organic pollution*

Fertiliser use in the SSP and Karjan commands will probably increase nutrients in the lower Narmada but, at present levels of use, leaching into rivers is not expected to be significant. This is mainly an issue for the Command Area study. Domestic wastewater is unlikely to increase substantially due to SSP but will increase with further expansion at Bharuch and Ankleshwar.

The main impact is the pollution and possible eutrophication of the estuary (Section 2.2.4).

2.2.4 *Anaerobic effects*

Reduced silt load (trapped by SSP) will increase water clarity and, therefore, photosynthesis. This added to any increase in the concentrations of nutrients and organic matter as discussed in Sections 2.2.1 and 2.2.3 may result in eutrophication of the estuary, after Stage 2, unless inhibited by an increase in toxic substances. The strong tidal currents may also serve to inhibit this.

2.2.5 *Gas emissions*

No direct effects on air pollution or greenhouse gas emissions are expected except to the extent that hydropower generation will reduce the need for thermal power generation (by decreasing amounts) up to Stage 3.

2.3 Soil properties and salinity effects

2.3.1 Soil salinity

Project-related changes are only relevant in the Command Area.

2.3.2 Soil properties

Project-related changes are only relevant in the Command Area.

2.3.3 Saline groundwater

Changes in salt concentrations in the groundwater due to irrigation percolation and seepage flows are only relevant in the Command Area. Seepage of water from the dam is not likely to be a significant.

2.3.4 Saline drainage

Sources of data on water quality are discussed in Appendix 5. Salt concentrations in regenerated water from the SSP and Karjan commands will be higher than in the supplied water but the concentrations are not expected to be significant with current low levels of fertilizer use. The principal impact of any such change would be on the freshwater intakes around Jhanor (Section 2.3.5). However, up to Stage 2 the regenerated water will be mixed in the monsoon period, with flows from tributaries downstream of SSP and, in the non-monsoon period, with power releases from SSP (likely to produce lower salinity levels than at present). In Stage 3, regeneration flows from irrigation will be the main source of flow in the non-monsoon period so salt concentrations may be important but salinity intrusion at the estuary is also relevant in this scenario (Section 2.3.5) so the two effects must be considered together.

2.3.5 Saline intrusion

Data sources on salinity in the estuary are described in Appendix 4.

Increased ingress of saline water from the estuary due to reduced river flows may have an impact particularly on the freshwater intakes around Jhanor, see Figure 1. Table 1 gives details of the locations and abstraction rates of existing and planned intakes and of the population or industry supplied. Various time periods must be considered.

- Immediate (during dam closure/impoundment)
  Dam closure will occur in April/May during the non-monsoon period when tributary flows are likely to be negligible (see Appendix 3).

- Up to Stage 2
  Increased flows in the non-monsoon period, and monsoon flows at least as great as those in the non-monsoon period, will lead to a reduced likelihood of saline intrusion.

- After Stage 2
  Reduced flows particularly in the non-monsoon period are likely to allow salinity ingress. In addition, the remaining freshwater flows may provide insufficient good quality water to meet demand.

The Central Water and Power Research Station (CWPRS) in Pune is currently undertaking a study for NPG, as described in Appendix 4. This will provide an estimate of the minimum flow required to allow freshwater abstractions at the rates shown in Table 1 in the river reach between Angareswar and Jhanor.

Salinity intrusion into groundwater towards the estuary and Gulf of Cambay due to excessive pumping is an existing problem (hence the decision of the Gujarat Water Supply and Sewage Board to build an intake from the Narmada River for the Narmada Bara Rural Water Supply Project.

As with impacts on groundwater level (Sections 2.1.4 and 2.1.5) the overall impact of SSP on salinity intrusion to groundwater in the downstream reach is most likely to be positive at all stages but may be negative as Stage 3 is reached. If increased salt water intrusion occurs due to changed river flows, the main impact would be on wells and boreholes of villages along the river in the tidal reach.

2.4 Erosion and sedimentation

2.4.1 Local erosion

Project-related changes are only relevant in the Command Area.

2.4.2 Hinterland effect

Not applicable.

2.4.3 River morphology (also
2.4.4 Channel structures)

Data on sediment loads in Narmada prior to SSP are available from the Central Water Commission for Garudeshwar and upstream from 1962 to the present. In most years, over 80% of the sediment was finer than 75µm.

It has been calculated that Sardar Sarovar Dam will trap at least 94% of the incoming sediment load and that once Narmada Sagar Dam is completed the proportion of sediment trapped will be even higher. The sediment which passes SSP will comprise only the finest particles and will be released almost entirely during the periods when flood discharges pass over the spillway.

Downstream of Sardar Sarovar the channel has a rocky bed for 10 or 20km after which the bed material changes from sands to fine sands and silts as the estuary is reached. At a site 26km downstream of the dam, a quarry has been established to extract 600 to 700m^3 of bed sediment per day to provide aggregate for the concrete of the dam.

Samples of bed material have been collected at 20km intervals during February 1993 to provide data for the morphological studies by CWPRS Pune. The banks are steep, standing 20 to 30m above the channel. They are generally of a finer material than the bed; samples collected by the consultants contained a large proportion of particles less than 75µm, varying from 65% at Garudeshwar to 96% at Jhanor.

The downstream morphology will also be influenced by the effect of the dam on flows. There will be a reduction in the frequency, magnitude and duration of flood flows which are the main channel forming agents.

A longitudinal profile of the river downstream of Sardar Sarovar is given in Figure A4.1. This shows a channel gradient of the order of 1:4000 in the first

45km and thereafter 1:10000. A study of old maps by CWPRS Pune shows the channel in the lower reaches approaching Bharuch to be relatively stable over a period of 130 years although minor adjustments due to bank scour and the reworking of sand banks are evident.

A study of channel morphology is being undertaken by CWPRS Pune (see Appendix 4) and once their report is available a more quantitative assessment of the impacts of SSP will be possible. In the meantime qualitative assessment suggests the following as the main impacts:

- Immediate effects up to Stage 1. This is the period of maximum erosive potential downstream of SSP. There will be very little sediment and flood flows will be less attenuated than later. Degradation of the channel is anticipated but is unlikely to affect the five downstream bridges or the freshwater intakes since they appear to have adequate scour protection. Deepening of the channel may lead to reduced flood levels especially in the reach between Garudeshwar and Jhanor (Section 2.7.9).

- After Stage 1. Further erosion is unlikely after Stage 1 since flood peaks are progressively reduced. Eventual narrowing of the channel may occur as the river assumes a new regime size. In the long-term this could affect the siting of the freshwater intakes. Bank protection has been provided at the freshwater intakes and by Bharuch which should be adequate since the channel is not expected to be any less stable than without the dam.

Apart from physical impacts such as those considered above, a change in particle sizes in the bed material may occur in either phase with possible impacts on aquatic flora and fauna.

2.4.5 Sedimentation

Reservoir sedimentation is the subject of a separate study. Canal and command area sedimentation has also been separately considered.

2.4.6 Estuary erosion

Available data on the estuary, its morphology and tides, are summarised in Appendix 4. Current studies by CWPRS Pune are also described there. Until the results of the CWPRS work become available only a qualitative assessment of the impact of the dam on the estuary can be made. Decreased river flow, especially after Stage 2, and the resulting increase in saline intrusion (Section 2.3.5) are likely to result in silting up of the estuary and the creation of a narrower channel. Changed estuary morphology will affect the mixing of fresh and sea waters and therefore affect water quality (Section 2.2.4). Predictions about future changes in estuary and morphology may, therefore, be needed to support any future water quality study.

If siltation occurs at the head of the estuary, it is possible that flood levels will rise at Bharuch.

2.5 Biological and ecological changes

As noted earlier, in Section 1.3, the environment of the lower Narmada valley has already been extensively modified by human activity. A study based on 1966 aerial photographs (MS University, 1983) revealed the following proportions of different land uses in the downstream reach: agricultural land 40%, forest area 27%, erosion land 26%, other (river, sandy area, habitation), 7%. However, close scrutiny of the maps shows that virtually all the forest identified in this region lies in the upper reaches of the basin of the Karjan tributary (upstream of the Karjan Dam) and is, therefore, unlikely to be directly affected by the changes resulting from SSP.

2.5.1 Project lands

Relates to the Command Area.

2.5.2 Water bodies

The reservoir is included in the upstream study area.

Changes described in 2.1.1-2.1.3, 2.2.1-2.2.4, 2.3.4, 2.3.5, 2.4.3-2.4.5 are likely to affect aquatic biology in the river and estuary. MS University did an initial study. Base-line data have also been collected by the Institute for Oceanographic Studies and the Central Inland Captures Fisheries Research Institute. A further study is currently being conducted by the Department of Environmental Sciences JN University, Delhi for NPG under a broad terms of reference covering the ecology of the entire lower Narmada. This study will be completed early in 1994. The biggest impact is likely to be seen in commercial fisheries (Section 2.5.8).

Little information is available on the marine ecology at the mouth of the estuary but the Gulf of Cambay is not noted as a productive fishing area. Without further information it is not possible to assess the extent that changes in water quality and sediment load at the mouth of the Narmada will have on marine ecology but previous studies have not raised this as a major issue.

2.5.3 Surrounding area

Not applicable. SSP does not really have a 'hinterland' since it encompasses such a large area.

2.5.4 Valleys and shores

Studies by MS University, Bhopal University and Ujjain University in the reservoir impoundment zone have not shown cause for concern over serious ecological damage to shoreline environments. The studies by JN University downstream of the dam will include a rapid survey of river-bank ecology during February 1993.

2.5.5 Wetlands and plains

The Floodplains of the Narmada under natural conditions are inundated about once in two years for relatively short periods, see Appendix 3. There are no large areas of natural vegetation, mostly non-intensive farming. Such areas may lose a source of nutrients from sediment deposited by the floods but there are no data available on this. Farmers on the floodplains will benefit by receiving irrigation.

No extensive areas of mangrove remain and around the south of Aliabet Island in the estuary the small areas remaining are reported as having been affected by the natural silting of the southern channel (SSNNL, 1992). Plans by NPG to manage better the resources of the island may include attempts to increase the area of mangrove.

2.5.6 Rare species

The studies so far conducted have not identified any rare or endangered species anywhere along the Narmada valley and, to date, no-one has raised this as a possible issue.

2.5.7 Animal migration

The only effect envisaged in the downstream region is an impact on the migration of hilsa and giant freshwater prawn due to the changed flow regime with a resulting impact on commercial fisheries (Section 2.5.8).

2.5.8 Natural industry (including fisheries)

Available reports on fish species and catches and numbers of fishermen are summarised in Appendix 6 which also includes details of ongoing studies by CICFRI. To date, there is a lack of detailed studies which would reveal important information on fish behaviour (breeding sites, conditions which favour migration). A report is being prepared for NCA by CICFRI giving an overview of the likely impact on fisheries. Without access to this report the following impacts are put forward as likely to be the most important.

- Hilsa: Changed flow patterns during the monsoon could affect migration which appears to be triggered by freshwater flows at the estuary mouth. Also changes in the duration of flows greater than a given threshold may affect the success of fry in reaching maturity. Finally, changes in the composition of river bed sediments may also affect spawning success. Consideration of hydrological changes in Appendix 3 suggests that there will almost certainly be an effect on hilsa after Stage 2. However, current knowledge is insufficient to predict with precision how soon the modifications of monsoon flows by the dam will begin to have a noticeable impact on catches. An impact on hilsa spawning may affect the incomes of marine fishermen who catch hilsa at sea but data on the significance of hilsa in marine catches are not available.

- Giant Prawn: Migration of giant freshwater prawn is in the reverse direction to that of hilsa. Spawning, in this case, takes place in the mouth of the estuary. This pattern of breeding is less likely to be affected by flows than that of hilsa but spawning would probably be affected by salinity intrusion and water quality changes in the estuary. It is not known if the dam will form a physical barrier to the migration of adult prawns.

- Other fish: Most other species are likely to be unaffected unless flows fall very low. Some species may be benefitted if mangrove is reintroduced around Aliabet Island.

The impact of the above changes on fishermen will depend on how readily they can adapt to alternative forms of employment (marine or culture fisheries, carpentry, farming). A study of the sociology of fishing families was undertaken by CICFRI.

2.6 Socio-economic impacts

2.6.1 *Population change*
No significant changes are expected in the downstream zone due to SSP.

2.6.2 *Income and amenity*
Positive impacts are expected in the Command Area. Possible negative impacts will be felt by fishermen (Section 2.5.8). Reduced flood risk may increase property values in Bharuch and the floodplain villages

2.6.3 *Human migration*
Not significant in the downstream zone due to SSP.

2.6.4 *Resettlement*
Not significant in downstream zone.

2.6.5 *Women's role*
No significant changes in the downstream zone due to SSP.

2.6.6 *Minority groups*
No significant minority groups live in the downstream zone.

2.6.7 *Sites of value*
None are likely to be affected in the downstream zone.

2.6.8 *Regional effects*
SSP is the linchpin of Gujarat's regional development plans for the whole region north of the Narmada (Section 1.2). Regional effects have been an integral part of its planning.

2.6.9 *User involvement*
This issue is largely restricted to the Command Area but consultation with fishermen affected by downstream changes is required.

2.6.10 *Recreation*
There are no significant recreational activities in the downstream zone at present but opportunities exist for development of the lower Narmada (up to Stage 2) in the same way as has happened downstream of Ukai Dam (see SSNNL, 1992).

2.7 Human health

2.7.1 *Water and sanitation*
Effects related to village wells and river offtakes are discussed in Section 2.3.5. An improvement in both the availability and quality of water are envisaged before Stage 2. Thereafter the reliability and quality of these sources are likely to deteriorate unless minimum flows are maintained in the river. Direct use of river water for laundry, bathing and domestic water are also likely to be affected after Stage 2 but the number of people affected is unknown.

2.7.2 Habitation

No significant changes in habitation are envisaged in the downstream zone due to SSP.

2.7.3 Health services

Existing services will continue to operate and no sudden changes in population numbers will occur. Therefore no additional resources will be required in the downstream zone as a result of SSP up to Stage 2. Thereafter, there is a possibility of increased risk of disease due to impaired domestic use of river water (Section 2.7.1) and increased malaria risk (Section 2.7.6) which the authorities should monitor. The special needs of dam construction workers are not included in the downstream considerations.

2.7.4 Nutrition

Irrigation is likely to improve nutrition. Loss of fisheries will not have a major adverse effect since a high proportion of the population are vegetarian and most of the hilsa catch is sold for consumption outside Gujarat.

2.7.5 Relocation effect

Little relocation is envisaged in the downstream zone due to SSP.

2.7.6 Disease ecology

Prior to Stage 2, increased flows in the Narmada River in the non-monsoon period will reduce the opportunities for mosquitoes to breed. After Stage 2 this may be reversed especially immediately below the dam in periods when no releases are occurring. Isolated pools will provide ideal breeding sites. Occasional releases of water for peak power generation, say once a week, would be beneficial in flushing out larvae as was practised for a time at Polgolla Barrage on the Mahaweli Ganga, Sri Lanka.

2.7.7 Disease hosts

No change is expected due to SSP.

2.7.8 Disease control

Environmental manipulation is unlikely to be the most appropriate means to control malaria in the river reach downstream of SSP except so far as power releases can be timed to give maximum effect in flushing larvae (Section 2.7.6). The Health Authorities have control strategies for malaria which are active and continually being reviewed and updated since malaria is already a major concern in Gujarat.

2.7.9 Other hazards

Flood risk downstream of SSP is likely to be reduced, see Appendix 3. Further study of flood routing by CWPRS Pune is currently in progress. Flood alert procedures already exist in the Narmada basin. These are being improved and updated (see NCA, 1989) so that flood warnings will in future be more reliable and earlier. Unless flood zoning is introduced to restrict encroachment onto the floodplains (as has happened at Surat downstream of Ukai Dam), the benefits of reduced flood hazard will be lost. Initially (before Garudeshwar Weir is built) flood surges resulting from start-up of generating turbines may present hazard in the river reach immediately below dam. After the weir is built (in 1996 or 1997) all such surges will be attenuated. The current CWPRS study of flood wave propagation may be used to study the likely magnitude and danger of such surges.

2.8 Ecological imbalances

2.8.1 Pests and weeds
Relevant only to the Command Area.

2.8.2 Animal diseases
No changes expected in the downstream zone due to SSP.

2.8.3 Aquatic weeds
Increased non-monsoon flows will reduce the likelihood of aquatic weed colonisation up to Stage 2 but they may become a problem in the lower reaches and estuary at a later stage.

2.8.4 Structural damage
No such damage is expected since SSP is a concrete dam.

2.8.5 Animal imbalances
Not expected in the downstream zone as a result of the dam.

3 Summary of main negative impacts and scope for mitigation

3.1 Flood risk (see 2.1.2, 2.4.6 and 2.7.9)
Overall the risk of downstream flooding will decrease due to the storage and attenuation of flood flows by SSP and other upstream reservoirs. Nevertheless, a definite risk remains. Prior to Narmada Sagar Dam, a large flood occurring in the second half of the monsoon period may be attenuated by less than 20%. Also, siltation at the head of the estuary, if it occurs, would increase flood levels at Bharuch although the overall risk, given reduced flows, is likely to remain less than at present. Against this, the flood warning system is being substantially upgraded so that communities at risk should receive better warning.

The principal danger is that reduced flood risk will lead to encroachment onto the flood-prone land which may negate any benefit obtained. Using the models being developed at CWPRS, Pune, it will be possible to quantify flood risk more precisely and decide whether a policy of flood zoning should be implemented.

3.2 Salinisation of groundwater (see 2.1.4, 2.1.5, 2.3.3)
This impact relates primarily to the Command Area. There is a slight possibility of a negative impact on village wells along the lower Narmada in Stage 3 due to reduced river flows but recharge from irrigation is likely to counteract this and give an overall positive impact. If any wells become unusable, domestic water can ultimately be supplied by building piped water supply systems fed from the irrigation canals.

3.3 Water quality in lower Narmada (see 2.2.1-2.2.4)

There is an increasing possibility of high concentrations of pollutants in the lower river and estuary after Stage 2 (produced by a combination of reduced flows and increased inputs from growing urbanisation/industrialisation). Ultimately this may also create the possibility of eutrophication in the estuary. Although the cause is due only partly to the dam, it is appropriate to review the potential for controlling pollution as an important aspect of the management of the lower Narmada. Three mitigation options are available

a) Increase flows in lean periods. The idea of a compensatory flow from Sardar Sarovar was rejected by NWDT. It should not, however, be totally ruled out especially at the Tribunal review in 2024. It is more likely to be acceptable if its purpose is not solely for pollution control but arises because power generation becomes a higher priority than currently envisaged as is quite likely in Stage 3. Compensatory flows are also likely to benefit water supplies (Section 3.4) and health (Section 3.9).

b) Improve treatment and control of effluents. The Pollution Control Board has a mandate to do this and takes its responsibilities seriously. In time, this will certainly make an important contribution.

c) Construct effluent outfalls into the Bay of Cambay. The new outfall from Ankleshwar is being located half way along the estuary and could, presumably, be extended at a later date.

3.4 Salinity intrusion affecting freshwater intakes near Jhanor (see 2.3.4 & 2.3.5)

a) Immediate impact during closure of the construction sluices at SSP and concreting the stilling basin apron. The likelihood of an adverse impact at this time is high, albeit for a fairly short period. Mitigation can, however, be provided, if planned in advance, by providing releases from Karjan Dam sufficient to keep the salinity below Angareswar and supply the needs of the intakes, since the dam currently has spare capacity. For short periods some needs could be met from previous groundwater sources.

b) Long-term impact (after Stage 2) when monsoon and non-monsoon releases from SSP may be zero in some years. Apart from loss of industrial water, 450,000 people will, by then, be depending on the intakes for domestic water. Two options for mitigation exist:

   - Either, investigate the desirability of releases from SSP to guarantee the required minimum flow (taking account of downstream contributions). As discussed in 3.3 this has a number of advantages but is likely to occur only if guaranteed levels of power generation become a priority in Stage 3.

   - Or, plan for eventual transfer to supplies provided from the canal system. One distributary from SSP passes close to Jhanor.

3.5 Morphology of the river reach (see 2.4.3 and 2.4.4)

Although there do not at present appear to be any major adverse impacts likely to result from changes in channel morphology (degradation or lateral movement) the issue must be reviewed when the results of the current study by CWPRS become available. In particular, the effect of aggregate quarrying in the river bed for dam construction and the possible impacts on flood levels, bridge structures, bank stability and bed sediment composition of predicted changes are the issues which must be addressed. Unless armouring effects are included in the CWPRS study their results are likely to over-estimate the scour predictions.

3.6 Morphology of the estuary (see 2.4.6)

Although the extent and time-scale cannot be predicted without access to the results of studies currently underway at CWPRS Pune, it is fairly certain that siltation of the estuary and narrowing of the main channel will occur as annual and peak river flows decline in Stages 2 and 3. However, since the only craft now using the estuary are shallow boats not requiring permanent landing stages, disruption of navigation is unlikely. Estuary siltation may affect both flood levels at Bharuch (Section 3.1) and water quality (Section 3.3) but these are insufficient reasons to consider dredging or any other mitigating action. To enable water quality predictions to be made, further model studies to show the rate of siltation may be required at a later date.

3.7 Changes to flora and fauna (see 2.5.1-2.5.8)

Apart from changes within the Command Area, which are being studied separately, few changes in terrestrial ecology are likely to occur downstream of Sardar Sarovar due to the project. Changes are expected, however, in aquatic ecosystems, littoral ecosystems and possibly marine ecosystems related both to changed flow regimes and changes in water quality (largely after Stage 2) as discussed in Section 3.3. Baseline data have been collected which suggest that issues of genetic diversity are unlikely to arise and that the only mangrove forests remaining are already severely degraded. The major issue arising from possible changes caused by the dam relates to fisheries and this has been considered above (Section 3.8). However, a more complete biota study is in progress by J N University. A particular focus of this study will be the prediction of future biological change, particularly in fish stocks. In this, close collaboration will be required with CWPRS Pune and the integration of expertise from a range of disciplines. Extension of the study to include possible changes within the marine environment due to loss of sediment, nutrients and freshwater from the Narmada is desirable.

Although damage to mangroves is unlikely to result from the dam, a plan currently under consideration to rehabilitate Aliabet and Tarawa Islands provides an opportunity to re-establish some of the previously degraded forests.

There is a slight possibility of ecological (and human) risk arising from poor quality water released from the Sardar Sarovar Dam (Section 2.2.2) particularly if anaerobic conditions are created at depth which favour H_2S production. Once the reservoir is impounded, limnological monitoring may be advisable to provide warning of any such danger. Judicious use of the sluice gates may be sufficient to avoid problems if any risk presents itself.

3.8 Decline of fisheries (see 2.5.8)

The eventual decline of hilsa and giant freshwater prawn fisheries seems highly probable, certainly after Stage 2, although some initial increase may result due to higher non-monsoon flows in the early phases. The exact timing of any decline cannot be predicted at the present state of knowledge.

The loss of hilsa would be significant in relation to stocks on the west coast of India but not in relation to global resources. Thus, loss of genetic resources is not an issue either with hilsa or giant freshwater prawn. Likewise loss of fish supplies for consumption is not a major issue since new supplies will be provided from reservoir fisheries.

The most significant impact would be on the livelihoods of the fishermen. Recent estimates of the number of fishing families dependent on stocks in the Narmada River vary from 2200 to 4700. For many of these, fishing is not their sole source of livelihood. Estimating the monetary value of the losses they may suffer is difficult both because of the lack of financial statistics and the variability in annual production but income losses in the range of US $ 11 to 25 million, at 1993 prices, are probable in the long-term (see Appendix 6). The overall economic impact on the region cannot be judged from current information but losses in the lower Narmada are expected to be more than offset by increased culture fisheries in the command area.

The following mitigating strategy has been proposed to ensure that fishermen do not suffer (SSNNL, 1992).

- Retrain and equip fishermen with boats more suitable for marine fishing in the Gulf of Cambay. This is a feasible option for fishermen in villages within the estuary although the economic viability of additional marine fisheries, part of which currently relies on marine catches of hilsa, should be investigated.

- Retrain and equip as culture fishermen in brackish ponds on coastal mud flats and freshwater ponds inland. In general, catch fishermen do not adapt readily to fish farming but many hilsa fishermen are already part-time farmers so the changes may not be too severe. The potential for fish farming is large.

- Retrain and equip for reservoir fisheries. Undoubtedly there is a large potential for reservoir fisheries which, it is estimated, will more than off-set any loss of estuarine and river fisheries. However, it does not seem appropriate for river and estuary fishermen to move to new locations around the SSP reservoir so this cannot be considered as an option for their rehabilitation.

- Employ the fishermen in hilsa, carp and giant prawn breeding stations to supplement natural stocks in the river after Stage 1 and to supply hilsa to the SSP reservoir and to brackish ponds in the estuary and giant prawn to the freshwater ponds. The artificial rearing of hilsa has proved to be viable but relies on obtaining spawn from adults caught in the estuary. Whether this cycle could be maintained if hilsa migration ceases in unknown.

- Equip fishermen to switch to activities which they had previously practised part-time. Many of the riverine fishermen already spend the period when hilsa are not in season engaged in other occupations such as carpentry and farming.

In addition to the above, fishermen may choose to move to one of a wide range of industrial and agricultural employment opportunities which will present themselves in the region as current plans for development take shape.

3.9 Malaria and other health risks along lower Narmada (see 2.7.1, 2.7.6 and 2.7.8)

There is a possibility after Stage 2 of enhanced breeding of the principal rural vector of malaria, Anopheles culicifaces, in pools in the dry river bed between the dam and, say Jhanor but occasional flushes of water for peak power generation will help to prevent this. In addition, loss of flow might present enhanced disease risk to villagers who use the river for domestic water.

The possible increase in malaria risk can be addressed within the established malaria control strategy of the Health Department although they may need to establish a specific programme of monitoring once the river flow conditions begin to favour transmission.

Deliberate flushing of the river, may be achieved without conflicting with power considerations, but the extent of any such flows in Stage 3 is at present problematic (Section 3.3).

3.10 Flow surges due to power generation (see 2.7.9)

There is a risk of surges in the river immediately below SSP in the period before Garudeshwar Weir is built. A temporary warning system may have to be installed to prevent danger to villagers using the river.

4 Monitoring, predictive studies and other recommended actions

A number of recommendations arise from the consideration of possible negative impacts taking into consideration the current studies in hand. These are summarised in Table 2 and described below under different time horizons. Table 2 includes an estimate of the resources required to implement the recommendations.

4.1 Immediate recommendations

The two immediate recommendations set out below should both be given high priority.

a) A plan of action should be devised to prevent the short-term loss of flow, during the period when the initial impoundment of the reservoir is occurring, from jeopardising the freshwater intakes near Jhanor. This requires estimation of the minimum flow requirement (based on the results of current salinity intrusion studies by CWPRS) and action to ensure that timely releases from Karjan Dam can be made to supplement the flow as required. Provided that the CWPRS results are adequate the resources needed to prepare this plan are minimal.

b) The CWPRS study of flood wave propagation should be extended to include a more detailed study of the reach immediately downstream of

Sardar Sarovar with the objective of studying the nature of any flow surges which may result when one or more turbines are switched on. If, in any reach, the flood wave is sufficiently steep to endanger villagers using the river, a hazard warning system should be introduced until such time as the Garudeshwar Weir is completed. The collection of additional cross-section data and hydraulic modelling are not major tasks provided the basic model is available. A period of 2 months should be adequate for the study.

4.2 Recommendations for the short-term (one or two years)

Some of the recommendations set out below carry few cost implications. The items of highest priority are a), b), c) and f).

a) Clarification is required over the implementation of mitigation measures for the rehabilitation of fishermen affected by the loss of hilsa and other fish catches. Notwithstanding the range of options available (Section 3.8) three questions require further clarification. In the first instance these are policy matters but they will lead to a number of activities which must be funded:

- Who will be responsible for monitoring the changing situation of the fishermen and implementing plans for their rehabilitation? The Gujarat Department of Fisheries is already closely involved in all aspects of the fisheries impact of SSP but a more specific mandate and allocation of funds may be necessary in relation to this task. In view of uncertainty in the timing of any significant impacts on hilsa productivity, monitoring should start immediately. (Data on catches are already being collected as part of the routine work of the department and can be used for this purpose but additional data are required including preparation of a definitive list of fishermen likely to be affected). In addition, the fishermen themselves should participate actively in the rehabilitation planning and implementation.

- To what extent and in what way will compensation be provided to the fishermen? A range of alternatives exists from single, direct cash payments (which might be difficult to apply in view of the gradual nature of the decline in fisheries and possible uncertainty as to who might be eligible), to government investment, in lieu of compensation, in equipment and tools necessary for redeployment as well as the provision training programmes. A clear policy on this question should be formulated in advance of any changes occurring and necessary preparatory work, such as the establishment of a hatchery, implemented.

- What regulatory measures is it appropriate to introduce for fisheries in the lower river? Given the likely increased competition for supplies as fish stocks decline, legislation should be prepared for use when it is needed (see Appendix 6).

b) The current work of CICFRI should be expanded in scope to include direct observations of fish behaviour and fish ecology in the river and estuary to provide the necessary information for subsequent predictive modelling in which the impact of hydrological changes and resulting biological changes can provide the basis for estimates of the impact on fisheries. This should be possible within the scope of their existing funding. NPG should also convene a Workshop on hilsa to enable existing knowledge to be synthesised.

c) Regular monitoring of water quality (particularly salinity), if not already in progress, should be introduced at the freshwater intakes near Jhanor and any observed change should be related to the river discharge and tidal conditions at the time. A salinity probe or conductivity meter may be adequate for this purpose in which case the cost will be relatively small.

d) The current study of flood wave propagation by CWPRS should be extended to provide a realistic assessment of downstream flood risk at all stages of upstream development using natural or synthetic data series. Account should be taken of expected bed level changes due to aggregate quarrying, channel scour and estuary siltation (if any) and this may require further morphological modelling. On the basis of these results and the expected benefits of the improved flood warning system, decisions should be made as to the possible need for a flood zoning policy particularly around Bharuch. This is a fairly substantial task requiring further numerical modelling, analysis of risk and formulation of policy proposals. It may require a study of 6 months duration or longer.

e) If not already planned, a regular (monthly) programme of water quality measurements at different depths in the Sardar Sarovar reservoir should be introduced at, say, three locations along its length depth. Although principally of limnological and fisheries interest these data will also provide warning of the likelihood of poor quality discharges downstream. The programme should, therefore, be set up so that amongst its objectives is a specific mandate to provide warning of possible risks in the downstream reach. Since the monitoring is likely to be established for reasons other than downstream impacts, the additional costs of implementing this recommendation will be negligible.

f) The regular collection of water quality data in the river and estuary should be reviewed to establish the minimum data requirement for future water quality management (in consultation with biologists and fisheries expects, see Appendix 5). Establishment of a single co-ordinating agency for such monitoring (possibly the GPCB) would avoid the present duplication of effort and resources. The recommended action is to seek more effective utilisation of resources already used for water quality monitoring although some additional funds may be needed to ensure that all the necessary data are collected.

g) Review the CWPRS study of morphological changes as recommended in Section 3.5 above.

4.3 Recommendations for the medium-term (five to ten years)

The items listed below, apart from b) and c) interrelate closely with each other and may be viewed as a single integrated study of the lower river and estuary to answer a number of questions. These questions should receive high priority as Stage 2 approaches.

a) A more detailed study of the likely pattern of monsoon and non-monsoon flows in the downstream tributaries should be combined with predictions of the release patterns from SSP once its mode of operation becomes *established so that a realistic assessment can be made* of the probability of minimum flow levels in the lower river. The assessment should be updated as further upstream development takes place and should be used as the basis for predictions about the risk of saline water entering the freshwater intakes and of other water quality changes in the estuary. Some of this work is in progress under CWPRS but further study may be needed.

b) The use of well and river water for domestic purposes by villages along the river should be studied and the level and quality of well water monitored periodically so that predictions can be made as to the likely impact on rural water supplies of changing patterns of river flows. Initially a short survey of the current situation will be adequate but this should be followed by ongoing monitoring.

c) Once the stage is reached when no water is released from Sardar Sarovar for periods of longer than a week, a study should be made of the possibility that increased mosquito breeding in pools of the river channel will cause malaria transmission to increase. Again a relatively brief initial survey will be needed to assess the situation before recommendations can be drawn up for further work.

d) A comprehensive study should be made of water quality changes as Stage 2 approaches. This will probably involve the creation of a water quality model for the river reach (1-D) and the estuary (2-D or 3-D) regions so that the changes in biological productivity and possible eutrophication can be examined. Such a model would be linked directly or indirectly to the tidal, salinity and estuarine morphology modelling currently in progress. It will be relevant to predictions about the timing and extent of impacts on various fish species and may be used to test the suitability of alternative pollution control strategies (compensatory flows, better effluent treatment, alternative sites for effluent outfalls). The model studies envisaged are fairly complex and would require a period of at least six months work once the basic data have been assembled.

e) An overall assessment should be made of the potential costs and benefits of providing guaranteed compensatory flows of various levels of discharge so that a clear policy can be reached on its advisability. The cost of foregoing water for irrigation should be balanced against potential benefits in terms of power generation, protection of freshwater intakes, control of mosquito breeding (if any) and dispersal of pollutants. The issue may be considered either as a reallocation to different uses by Gujarat of its water rights under the existing NWDT or as the basis for a fresh application for compensatory flows when NWDT reconvenes in 2024. The assessment itself would not be complex but specifying the nature of the benefits may be difficult and would require inputs from appropriate experts.

f) Parallel with any policy decisions resulting from e), a decision is required as to the best means of safeguarding the freshwater supplies which are currently drawn from the intakes near Jhanor. If adequate minimum flow levels in the river cannot be guaranteed, timely plans must be made to supply these demands from the canal distribution network. The definition of the policy options would be a small task but there are cost implications of implementing either option.

g) As indicated in d), an integrated approach to downstream ecological changes is required particularly as they affect hilsa fisheries. This requires a team of specialists in hydrology (fully conversant with the operating policies for the dam), in water quality, in river and estuary morphology, in aquatic biology and in fish ecology to work together and examine the likely future changes as the pattern of discharges from SSP changes with time. The selection of the most appropriate coordinating body is an important one since, unless there is a clear understanding of the hydrological constraints and risks, much effort may be spent in preparing models and predictions which are not appropriate to the situation.

5 Conclusions

The Sardar Sarovar Projects are part of an ambitious and comprehensive plan for the future development of the entire Narmada basin and are integral to the current economic and social development plans of the states of Gujarat and Madhya Pradesh. The normal "with project or without project" type of assessment normally attempted for development projects is not really appropriate since the authorities in Gujarat cannot conceive of any means to meet the pressing needs for domestic and irrigation water north of the Narmada River without an intervention on this scale. Under such circumstances the purposes of environmental assessment are twofold:

a) to ensure that adverse environmental effects are minimised, that whatever appropriate mitigating measure are available are used and that groups in society who may suffer loss due to such changes are rehabilitated and/or compensated in a timely fashion.

b) to consider the long-term sustainability of the planned changes to the regions social, economic and environmental systems to ensure that such safeguards as are available are included in order that the danger of long-term deterioration and degradation are avoided to the best of current knowledge.

The SSP being a vast and complex set of projects, the environmental assessments have been split into a number of parts, the present report relating only to the downstream effects. With regard to these downstream effects item a) above is the main question under consideration since the changes which will take place in the region are 'side effects' rather than the planned changes resulting from provision of irrigation and domestic water and hydropower.

There will undoubtedly be a series of changes to the environment in the downstream region as the development of the SSP and upstream Narmada basin advances. The extent of these changes depends on the particular phase of development and most are linked closely with the hydrological changes which relate to the modified releases of water downstream of Sardar Sarovar Dam. It is clear, however, that much of the environment (both terrestrial and aquatic) in the lower Narmada valley has already undergone substantial modification due to the impact of human settlement, agriculture and industry and there are few, if any, habitats remaining which are 'rich' in ecological terms.

The principal downstream impacts resulting from the Narmada development plans have been identified by means of a draft 'Environmental Check-list' which has been developed for the Environmental Impacts Working Group of the International Commission on Irrigation and Drainage (Mock and Bolton, 1993). They are summarised in Section 3 of the report, the main items being:

- effects on fish stocks and related fisheries
- water quality changes affecting freshwater intakes and the ecology of the estuary
- possible effects on human health and flood risk.

In each case, requirements for monitoring and the options for mitigation are discussed. Recommended actions relating to the implementation of monitoring and mitigation measures are summarised in Section 4. Since some of these recommendations relate to changes which will take place immediately and others in the later phases of development, the recommendations are grouped under three headings: immediate, short-term and medium-term.

The timing of possible changes has not been discussed in great detail although a suggested time-frame for action under the three sets of recommendations given in Section 4. The main reason why timing has not featured more prominently in this report is that the extent and nature of the impacts is heavily dependent on the rate of irrigation implementation in Gujarat and Madhya Pradesh. The ultimate state envisaged, when all the development plans now envisaged have been implemented, has been given a notional date 45 years after work on Sardar Sarovar Dam began. Some people doubt whether implementation could be completed within this time or, indeed, will ever be implemented as currently envisaged. In relation to the downstream impacts the question of timing has little effect on the nature of the changes considered or the ability of the authorities to take effective mitigative action provided that changes are monitored and the rate of development reviewed on a regular basis. This is particularly important if changes in the operating policy of the dam are introduced, for example, giving high priority to hydropower generation. Careful attention should be paid to the monitoring of fisheries since it is not possible with present knowledge to predict the timing and extent of changes to hilsa spawning which will result from changes to the timing and magnitude of monsoonal flows.

The one issue which should be reassessed in the next ten years and regularly thereafter is whether it is feasible and appropriate to allow a minimum flow of water to be maintained in the lower Narmada. Water released through the turbines could complement downstream tributary flow to achieve these compensatory flows which would offer benefits in relation to freshwater supplies, pollution dispersal, aquatic biology and probably also human health.

The overall conclusion of the team undertaking the assessment described in this report is that there are no downstream impacts whose magnitude and effect are such as to cause doubts to be cast over the wisdom of proceeding with the Sardar Sarovar Projects provided that appropriate monitoring and mitigation measures are applied. Much of this, work is already in progress under the auspices of the NPG, SSNNL and NCA. The recommendations in this report are intended to provide a synthesis of their work and suggestions as to where it might be modified to enhance its usefulness.

6 Acknowledgements

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Tables

Table 1 Existing and planned fresh water intakes

Location	Design Abstraction Rate		Water Use
	(Mld^{-1})	(m^3s^{-1})	
Angareswar	22	0.25	Bharuch municipality (120,000 people)
Angareswar (same intake)	78	0.90	Gujarat Narmada Fertilizer Co.
Jhanor	32	0.37	Narmada Bara Rural Water Supply Scheme (300,000 people)
Jhanor	30	0.35	Oil and Natural Gas Corp. (includes water for 30,000 people)
Jhanor	40	0.46	National Thermal Power Corp. (for cooling towers and other uses)
Jhanor	15	0.11	Gujarat Industrial Devt. Corp. (small industries at Bharuch)
Total	217	2.50	

Table 2 Summary of recommended actions

	Action	Timescale	Priority	Staff time (months)	Approximate costs*	Comments
	Immediate					
1	Prepare plan to mitigate effects of initial dam closure	Minimal	High	Minimal	Minimal	Subject to availability of CWPRS results
2	Prepare plan to mitigate effects of surges from turbines	1 month	High	Local 1m	Rs 12 500	
	Short-term					
3	Prepare and implement policy for monitoring and mitigating effects on fishermen	Ongoing	High	Local 3m per year	Rs 37 500yr^{-1} plus direct costs	Direct costs include all costs of rehabilitation
4	Data collection and Workshop on fish ecology	2 years	High	Local 12m	Rs 150 000	Possibly met by redefining CICFRI's tasks
5	Salinity monitoring at freshwater intakes	Ongoing	High	Minimal	Minimal	
6	Study of flood risk to determine if flood zoning needed	6-9 months	Lower	Local 12m	Rs 150 000	
7	Monitor reservoir limnology to warn of poor quality releases	Ongoing	Lower	Local 1m per year	(Rs 12 500yr^{-1})	No additional cost if part of wider limnological monitoring
8	Coordinated monitoring of water quality in river and estuary	Ongoing	High	local 6m per year, Intl ½m	Rs 75 000yr^{-1} US$ 9 000	Cost might be reduced by rationalising existing monitoring and using water quality probes
	Medium-term					
9	Study of low flow hydrology and integration of items 12 to 15 below	3 months	High	local 4m Intl 1m	Rs 50 000 US$ 18 000	To be undertaken once Stage 2 operating policy for SSP established
10	Reconnaissance study of domestic water supplies close to river	2 months	Lower	local 3m	Rs 37 500	Study required once releases from SSP are cut for several weeks
11	Reconnaissance study of mosquito breeding in river channel	2 months	Lower	local 3m	Rs 37 500	As for 10
12	Water quality and salinity model of river and estuary and study of effluent disposal options	12 months	High	local 12m Intl 2m	Rs 150 000 US$ 32 000 plus software costs	May include further modelling of estuary morphology, Depends on 8
13	Assessment of costs and benefits of providing compensatory flows	2 months	High	local 2m	Rs 25 000	Depends on results of 9, 12 and 14
14	Policy options to safeguard freshwater intakes	2 months	High	local 2m	Rs 25 000	Depends on results of 9 and 12
15	Prediction of ecological changes particularly to fisheries	2 months	Lower	local 3m Intl 1m	Rs 37 500 US$ 18 000	Depends on results of 4, 9 and 12

* Assuming Rs 12 500 per month local and US$ 18 000 per month international.

Figure

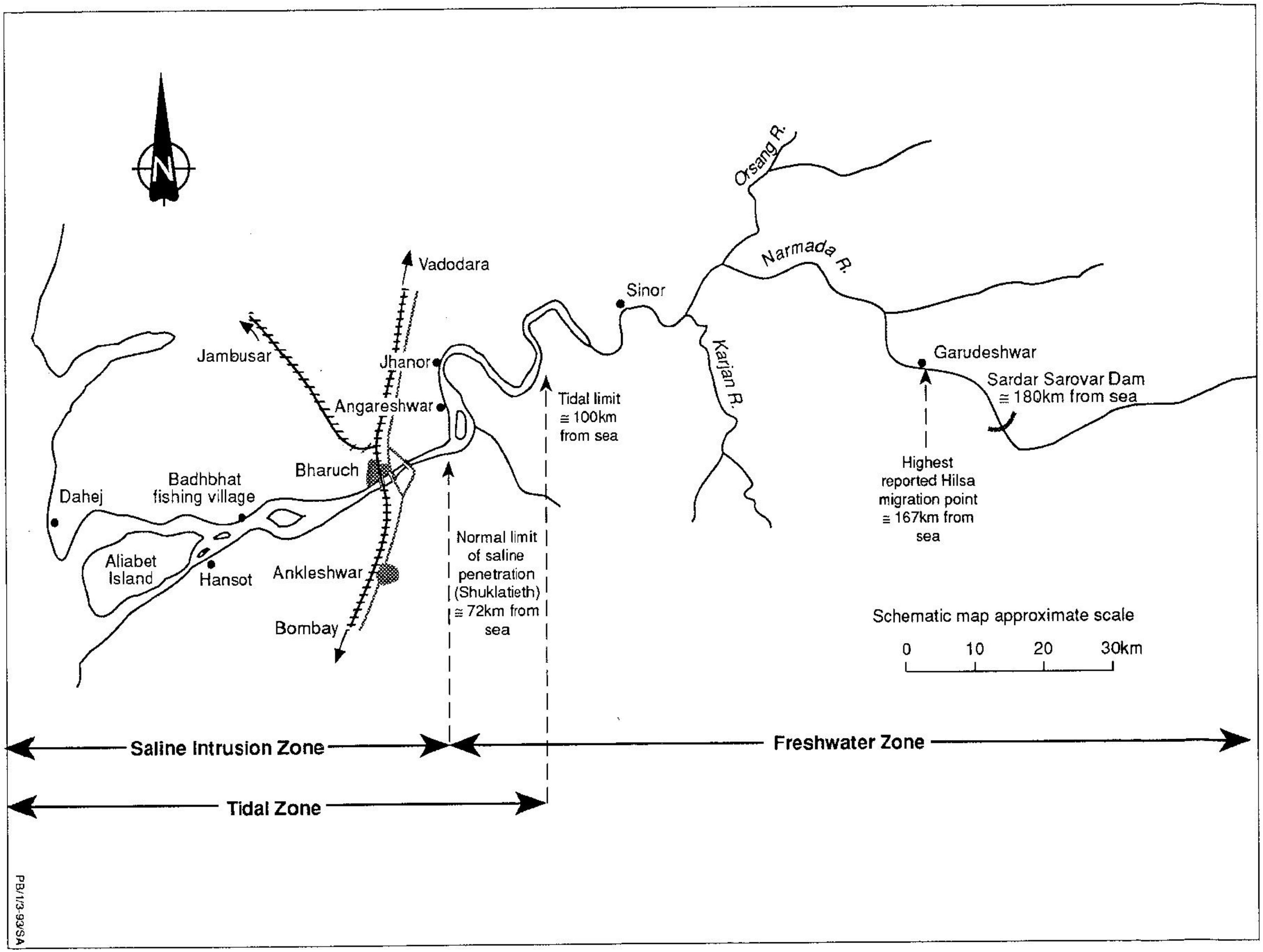

Figure 1 Lower Narmada river and estuary

Appendices

Appendix 1

Terms of Reference

INDIA-SARDA SAROVAR (NARMADA) PROJECTS
ESTUARY IMPACT
Terms of Reference (4)

1. Objective The objective of this consultancy is to (a) assist SSNNL in completion of ongoing environmental studies of the impact of the Sardar Sarovar dam on the Narmada river estuary (which for this purpose includes the portion of the river from the dam site in Gujarat to the sea). The studies are to take account of the latest estimates of probably water release patterns from the Sardar Sarovar dam and to provide a set of downstream scenarios which can be used to plan prospective ameliorative measures well in advance of potential impacts.

2. Scope of Work As noted above the studies focus on one stretch of the river and the impact of the SSP dam on that section. Consultants should initiate work by study of following documents : report of the Independent Review (Mores report) of the Sardar Sarovar Projects; responses of the World Bank management and the Government of India (mainly the Gujarat Narmada Nigam Ltd) to the assertions in the Morse report; studies by the Narmada Planning Group, the Central Water Commission, the Gujarat state fisheries department, the Central Institute for Inland Fisheries (Barrackpore) which is currently conducing estuary impact analysis with an office in Baroda, Gujarat; the draft Bank staff appraisal report for the proposed Narmada River Basin development project, which deals in part with impact of the SSP dam on estuary fisheries. Consultants should also liaise closely with representatives from the Environmental Resources Ltd, who will be conducting environmental studies in the same area.

3. In addition to document/literature review, consultants will be expected to visit India to discuss issues of the consultancy with appropriate officials in the World Bank office, Narmada Control Authority, Barrackpore Institute, Sardar Sarovar Project Authority, Central Water Commission, Gujarat State Fisheries Department.

4. On the basis of the aforementioned work, consultants will assist SSNNL in preparation of a report that (a) summarizes and renders a qualitative judgement on the environmental impact work completed to date or ongoing; (b) makes recommendations as needed for enhancing studies in the area mentioned above (ref para 1) (c) highlights any important gaps in the overall environmental analytical work in the section of the river from the SSP dam to the sea, along with suggestions for a prioritized work plan and estimated cost if such gaps are found; (d) recommends a program of institutional strengthening aimed at developing in Gujarat a reliable capability for monitoring systematically and over time environmental impacts downstream from the dam and a response capacity for developing appropriate mitigation measures as may be needed. This latter work will need to be closely synchronized with complementary work to be carried out by ERL consultants in assisting developing an environment overview report on the Sardar Sarovar Project and in helping prepare terms of reference for a wider Narmada Basin environmental management plan.

5. Terms of Consultancy Terms and conditions, including financial arrangements, will be spelled out in a separate letter from the Bank.

Revised version as per letter from T A Blinkhorn, World Bank, dated January 21 1993

Appendix 2

ICID Environmental Check-list
Detailed Descriptions

ICID CHECK-LIST OF POSSIBLE ENVIRONMENTAL EFFECTS
DETAILED DESCRIPTIONS AND RECORD OF FINDINGS

1. Hydrological changes

1.1 Low flow regime

Is the low flow regime of the river substantially changed by the Project and its dams (by more than ±20% in low flow periods) and does this benefit or impair aquatic ecosystems, existing or potential downstream abstractions, hydropower, navigation or recreational uses?

Findings:

1.2 Flood regime

Is the flood regime of the river (peak discharge and stage, speed of flood waves, flood super-position with joining rivers, duration or extent of floodplain inundations downstream) substantially changed by the Project as a result of changes in abstractions, retention storage, reservoir releases, flood protection works, new road/rail routes, river training or surface drainage works and does this lead to an increase or decrease in flood damage or change land use restrictions outside the Project?

Findings:

1.3 Operation of dams

Can modifications to the operation of any storage or flood retention reservoir(s) compensate for any adverse impacts associated with changes in flow regime, water quality downstream, saline intrusion, the sediment regime of channels, the ecology of affected areas, amenity values, disease transmission or aquatic weed growth, whilst minimising the losses to the Project and other users? (A separate environmental assessment of large reservoir(s) may be required).

Findings:

1.4 Fall of water table

Is a lowering of the water table (from groundwater abstractions, reduced infiltration due to river training, drainage or flood protection works) leading to increased potential for groundwater recharge (from seasonal rainfall) and improved conditions for land use or leading to depletion of the groundwater system, affecting wells, springs, river flows and wetlands?

Findings:

1.5 Rise of water table

Is a rise of the water table (from increased infiltration or seepage from irrigation, seepage from reservoirs and canals, or increased floodplain inundation) leading to improved yield of wells and springs and improved capillary rise into the roof zone or to waterlogging of agricultural or other land in the Project area or vicinity?

Findings:

2. Organic and inorganic pollution

2.1 Solute dispersion

Are changes to the pattern of water abstraction and reuse in the basin or flow regulation, due to the Project and its dams, leading to changes in the concentrations of organic or inorganic solutes in the surface water which can affect biological communities or domestic, agricultural or industrial water users in the basin?

Findings:

2.2 Toxic substances

Are significant levels of toxic substances, such as pesticides, herbicides, hydrogen sulphide, oil derivatives, boron, selenium or heavy metals, accumulating or being introduced, mobilised and transmitted in irrigation supplies or surface, drainage and ground waters due to the construction and operation of the Project and its dams or are levels being reduced?

Findings:

2.3 Organic pollution

Are nutrients, organic compounds and pathogens being reduced or introduced and concentrated, due to the Project, its dams and its associated domestic settlements, resulting in reduction or increase in environmental and water use problems in the Project area or downstream (in rivers, canals, reservoirs, end lakes, evaporation wet lands, depressions, deltas, estuary regions) or in the groundwater?

Findings:

2.4 Anaerobic effects

Is the Project reducing or creating anaerobic conditions or eutrophication in any impoundments, natural lakes, pools or wetlands due to changed input or accumulation of fertilisers, other nutrients and organic matter or due to changed water quality resulting from dams, river abstractions and drainage flows?

Findings:

2.5 Gas Emissions

Is the Project, either directly or through associated industrial processing, causing decreased or increased gas emissions which contribute to air pollution (O_3, SO_3, H_2S, NO_x, NH_4, etc) or the greenhouse effect (CO_2, CH_4, NO_x, etc)?

Findings:

3. Soil properties and salinity effects

3.1 Soil salinity

Is the Project leading to progressive accumulation of salts in the soils of the project area or the vicinity because of prevailing high salt content in, the soil, the groundwater, or the surface water; or can a progressive leaching effect be expected?

Findings:

3.2 Soil properties

Are irrigation, the application of fertilisers or other chemicals, cultivation practices, dewatering through drainage or other results of the Project leading to changes in soil characteristics within the Project area or the vicinity which can improve or impair soil structure, workability, permeability, fertility associated with nutrient changes, humus content, pH, acid sulphate or hard pan formation or available water capacity?

Findings:

3.3 Saline groundwater

Are changes to the rates of seepage or leaching from the Project and its dams increasing or decreasing the concentrations of chlorides, nitrates or other salts in the groundwater?

Findings:

3.4 Saline drainage

Are levels of salts in the drainage water in danger of affecting existing or potential downstream users (particularly during low flow conditions)?

Findings:

3.5 Saline intrusion

Are the Project and its dams (due to changes in low flow, groundwater use, dredging, river training) leading to changes in saline water (sea water) intrusion into the estuary or into groundwater affecting other areas and water users?

Findings:

4. Erosion and sedimentation

4.1 Local erosion

Is increased or decreased soil loss or gully erosion being caused within or close to the Project area by changes in land gradient and vegetative cover, by irrigation and cultivation practice, from banks of canals, roads and dams, from areas of cut and fill or due to storm drainage provision?

Findings:

4.2 Hinterland effect

Are the Project and its dams leading to changes in natural vegetation, land productivity and erosion through changes in population density, animal husbandry, dryland farming practices, forest cover, soil conservation measures, infrastructure development and economic activities in the upper catchment and in the region surrounding the Project?

Findings:

4.3 River morphology

Is the regime of the river(s) changed by the Project and its dams through changes in the quantity or seasonal distribution of flows and flood peaks in the river(s), the abstraction of clear water, changes in sediment yield (caused by 4.1 and 4.2), the trapping of sediment in reservoirs or the flushing of sediment control structures and do these changes benefit or impair aquatic ecosystems and existing and potential users downstream?

Findings:

4.4 Channel structures

Is scouring, aggradation or bank erosion in the river(s), associated with changes noted in 4.3 (whether or not caused by the Project and its dams), endangering the Project's river headworks, offtake structures, weirs or pump inlets, its canal network, drainage or flood protection works, the free flow of its drainage system or structures and developments downstream?

Findings:

4.5 Sedimentation

Are the changes noted in 4.1 - 4.4 causing increased or decreased sediment deposition in irrigation or drainage canals, hydraulic structures, storage reservoirs or on cultivated land, either via the irrigation system or the river(s), (affecting soil fertility, Project operation, land cultivation or the capacity and operation of reservoirs)?

Findings:

4.6 Estuary erosion

Are the Project and its dams leading to changes in the hydrological or sediment regimes of the river which can affect delta formation or estuary and coastal erosion?

Findings:

5. Biological and ecological changes

Is the Project, its dams or its associated infrastructure causing substantial and permanent changes (positive or negative) in the natural ecology (habitat, vegetation, terrestrial animals, birds, fish and other aquatic animals and plants), in areas of special scientific interest or in biological diversity within the habitats listed in 5.1 - 5.5?

5.1 Project lands

The project area.

Findings:

5.2 Water bodies

Newly created, altered or natural channels, reservoirs, lakes and rivers.

Findings:

5.3 Surrounding area

All terrestrial areas influenced by the Project works and its associated domestic settlements and hinterland effects.

Findings:

5.4 Valleys and shores

River and canal banks and lake, reservoir and sea shores.

Findings:

5.5 Wetlands and plains

Floodplains or permanent wetlands including deltas and coastal swamps.

Findings:

5.6 Rare species

Is the existence of any rare, endangered or protected species in the region enhanced or threatened by the changes noted in 5.1 - 5.5?

Findings:

5.7 Animal migration

Does the Project its dams or new road/rail routes affect the migration patterns of wild animals, birds or fish allowing for the compensatory effect of any additional provision within the Project (canal crossings, fish passes, spawning locations, resting or watering places, shade, considerate operation)?

Findings:

5.8 Natural industry

Are commercial or subsistence activities depending on the natural environment benefited or adversely affected by the Project (including harvesting from natural vegetation, timber, fisheries, game hunting or viewing, honey production) through ecological changes or changes in human access?

Findings:

6. Socio-economic impacts

6.1 Population change

Is the Project causing significant demographic changes in the Project area or vicinity (population size/density, demographic/ethnic composition) which may affect social harmony?

Findings:

6.2 Income and amenity

Is the Project introducing significant changes in the general levels of employment and income, in the provision of local infrastructure and amenities, in the relative distribution of income, property values and Project benefits (including access to irrigation water) or in the demand for labour and skills (particularly in relation to family/political hierarchy and different sexes and social groups) which can increase or decrease social harmony and individual well-being?

Findings:

6.3 Human migration

Has adequate provision been made for any temporary or migratory population influx, arising from the demand for skills/labour during construction and the requirements for seasonal agricultural labour, to avoid social deprivation, hardship or conflicts within these groups or between the permanent and temporary groups?

Findings:

6.4 Resettlement

Has adequate provision been made for the resettlement, livelihood and integration of any people displaced by the Project and its dams or losing land, grazing or other means of income due to the Project and for the subsistence farming needs of people settled on or associated with the Project?

Findings:

6.5 Women's role

Does the Project change the status and role of women (positively or negatively) in relation to social standing, work load, access to income and heritage and marital rights?

Findings:

6.6 Minority groups

Are the Project and its dams causing changes to the lifestyle, livelihoods or habitation of any social groups (particularly minority groups) leading to major conflicts with, or changes to their traditional behaviour, social organisation or cultural and religious practices?

Findings:

6.7 Sites of value

Is access improved or hampered to places of aesthetic and scenic beauty, sites of historical and religious significance or mineral and palaeontological resources or are any such sites being destroyed by the Project?

Findings:

6.8 Regional effects

Are the economic, infrastructural, social and demographic changes associated with the Project likely to enhance, restrict or lead to unbalanced regional development and has provision been made for transport, marketing and processing?

Findings:

6.9 User involvement

Has there been adequate user and public participation in project planning, implementation and operation, including incorporation of existing systems (land tenure, traditional irrigation, organisational and sociological structures) and new or extended facilities (credit, marketing, agricultural extension and training) to ensure Project success and reduce future conflicts?

Findings:

6.10 Recreation

Are the project and its dams creating new recreational possibilities (fishing, hunting, sailing, canoeing, swimming, scenic walks, etc) and are existing facilities preserved or improved?

Findings:

7. Human health

Consider each of the items 7.1 - 7.9 in relation to the local population, the labour force during construction and their camp followers, the resettled and newly settled populations and migratory labour groups.

7.1 Water and Sanitation

Are the provisions for domestic water, sanitation and refuse disposal such that oral, faecal, water washed and other diseases and the pollution of domestic water can be controlled?

Findings:

7.2 Habitation

Are the provisions for housing and forecast population densities such that diseases related to habitation or location of dwellings can be controlled?

Findings:

7.3 Health services

Are general health provisions adequate (treatment, vaccination, health education, family planning and other health facilities)?

Findings:

7.4 Nutrition

Is the Project leading to an increase or decrease in the general nutritional status of the population or to changes in other lifestyle or income related diseases and are any specific groups particularly exposed to such health risks?

Findings:

7.5 Relocation effect

Are population movements introducing new infectious or water-related diseases to the Project area or causing stress-related health problems or bringing people with a low resistance to particular diseases into areas of high transmission?

Findings:

7.6 <u>Disease ecology</u>

Are the extent and seasonal character of reservoirs, canals, drains, fast flowing waters, paddy fields, flooded areas or swamps and the closeness or contact of the population with such water bodies leading to significant changes in the transmission of water related diseases?

Findings:

7.7 <u>Disease hosts</u>

Are the populations of intermediate and other primary hosts of parasitic and water-related diseases (rodents, birds, monkeys, fish, domestic animals) and the interaction of the human population with these hosts, decreased or increased by the Project?

Findings:

7.8 <u>Disease control</u>

Can the transmission of the diseases identified in 7.1, 7.2, 7.5, 7.6 and 7.7 be reduced by introducing into the Project environmental modifications or manipulations (including removal of breeding, resting and hiding places of vectors or reducing contamination by and contact with humans) or by any other sustainable control methods?

Findings:

7.9 <u>Other hazards</u>

Is the risk to the population decreased or increased with respect to the following: pathogens or toxic chemicals present in irrigation water (particularly through wastewater reuse) or in the soils, which can accumulate in food crops or directly threaten the health of the population; dwellings adequately located and designed to withstand any storm, earthquake or flood hazards; structures and water bodies designed to minimise accident and allow escape?

Findings:

8. Ecological imbalances

8.1 Pests and weeds

Are crop pests or weeds likely to increase or decrease (particularly those favoured by irrigation/drainage/flood control) affecting yields, cultivation and requirements for pesticides or herbicides?

Findings:

8.2 Animal diseases

Are domestic animals in the Project or vicinity more or less exposed to hazards, diseases and parasites as a result of the Project and its dams?

Findings:

8.3 Aquatic weeds

Are reservoirs, rivers or irrigation and drainage canals likely to support aquatic vegetation or algae which could be harvested or could reduce the storage/conveyance capacity, interfere with the operation of hydraulic structures or lead to oxygen-oversaturated or anaerobic water bodies?

Findings:

8.4 Structural damage

Is there a danger of significant damage being caused to dams, embankments, canal banks or other components of the irrigation/drainage/flood control works through the action of plants and animals (including rodents and termites) favoured by the Project?

Findings:

8.5 Animal imbalances

Does the Project cause zoological imbalances (insects, rodents, birds and other wild animals) through habitat modification, additional food supply and shelter, extermination of predators, reduced competition or increased diseases?

Findings:

Appendix 3

The effect of Sardar Sarovar Dam on downstream flows

Appendix 3 The effect of Sardar Sarovar Dam on downstream flows

A3.1 Basic hydrological data and studies

The natural hydrology of the Narmada river has been extensively studied by the Central Water Commission and the Narmada Planning Group and a reliable sequence of natural flows (daily values) for the Garudeshwar gauging site close to Sardar Sarovar Dam obtained from 1948/49 to 1977/78 (30 years). These data were used in planning the Sardar Sarovar Dam and as the basis for the final decisions of the Narmada Waters disputes Tribunal. In addition, a generated flow sequence based on rainfall data going back to 1891 was also prepared. It is not within the current terms of reference to describe in detail the preparation of these data. The principal characteristics of the natural flows are: a strongly seasonal variation in which, during the five months of the monsoon (June to October), 93% of the annual flow occurs; and a relatively small variation in the total annual discharge (C_V = 37%).

The characteristics of the natural flow sequence and the anticipated changes resulting from the construction of Sardar Sarovar Dam and other projects within the Narmada basin were the subject of several detailed studies in the period leading to the publication of the World Bank Project Appraisal Report in 1985.

(a) A catchment runoff and flood routing model was used by CWPRS, Pune to predict the probable maximum flood at Sardar Sarovar Dam for the purpose of sizing the spillway;

(b) A reservoir operations model was used with daily flow data to predict the extent of flood attenuation which would occur if historical floods from the 30 year natural record were routed through the reservoir beginning from a condition at or near the normal maximum reservoir level. (Table A3.1)

(c) Various consultants and agencies (ORG, IMM, CEA) used reservoir operations models on a 10-day or monthly time-step using the 30 year data sequence to study the likely stream of benefits from the Sardar Sarovar Dam at various phases of its future development. None of these were specifically set up to study the characteristics of the downstream flows but the output from their models provided such data. Further discussion of the ORG models is included below.

A3.2 The Narmada Water Disputes Tribunal (NWDT)

The final order and decision of the NWDT in 1979 provided the framework on which not only the Sardar Sarovar Project but also the other proposed projects of the Narmada basin would proceed (see World Bank, 1985b, Annex 2 for full details). The decisions covered various aspects of the development of the Narmada basin but, in particular, the Tribunal treated the basin as a whole and allocated rights to water on the assumption that irrigation and other water demands throughout the basin states would expand into the future and that these future rights must be secured. The basis for the allocation was an assessment of the 75% dependable yield at Garudeshwar which was taken to be 28 MAF (34.5 x $10^9 m^3$). Of this Madhya Pradesh was allocated approximately 65%, Gujarat 32%, Rajasthan 2% and Maharashtra 1%. The

Table A3.1 Predicted and historical floods (1948-1980)

	Year/Probability	Peak flow ($10^3 m^3 s^{-1}$)	Peak flow routed through reservoir* ($10^3 m^3 s^{-1}$)
Predicted	1 in 100 1 in 1000 P.M.F	68.4 86.4 109.2	60.4 77.9 92.4
Recorded	1970 1973 1968	69.3 61.3 58.0	59.1 50.5 41.5
	1979 1972 1950	49.0 47.9 45.6	40.2 40.2 32.1
	1959 1961 1978	44.4 43.3 39.2	24.2 36.0 24.2
	1962 1975 1969	38.8 33.7 31.2	24.2 19.4 24.1
	1955 1957 1954	29.1 28.8 28.6	18.2 18.0 17.0
	1949 1980 1948	26.8 26.5 23.9	17.1 17.2 14.6
	1977	23.1	14.1

* Reservoir level begins 1.5m below normal full supply level (138.7m aMSL). The degree of attenuation depends on the shape of particular hydrographs.

allocation is to be made in the same ratios whatever the flow in a particular year.

The point of particular significance in the NWDT decision, with respect to downstream flows, was that the Tribunal recognised Madhya Pradesh's inability in the early years, to use its full allocation through consumptive use upstream. It was therefore given the right to utilise its remaining allocation as hydroelectric power releases from Sardar Sarovar in exchange for a contribution towards the project's costs. Thus, with time, it was anticipated that increasing amounts of water would be used by Madhya Pradesh for irrigation in the basin upstream of Sardar Sarovar and that the power releases (and hence downstream flows) from Sardar Sarovar would decrease accordingly.

For planning purposes, three distinct Stages of future development were proposed. In reality these are points on a gradually changing profile of predicted scenarios since, apart from Sardar Sarovar and Narmada Sagar, future development will occur in relatively small increments. The timescale and water use envisaged in each Stage are shown in Table A3.2.

Table A3.2 is only a planning forecast since any of the states may develop its consumptive use at a rate different from that envisaged in Table A3.2. In particular, current trends suggest that Madhya Pradesh may take more than the expected 45 years to develop its full consumptive demand upstream to the level of $22.5x10^4m^3$ whereas Gujarat may reach its Stage 2 level of consumption in less than 30 years.

Initially Gujarat applied to the NWDT for an additional allocation of $28.3m^3s^{-1}$ to maintain a minimum flow in the Narmada River downstream of Sardar Sarovar Dam. This application was turned down by the Tribunal.

The decisions of NWDT may be modified only by agreement with all the basin states. The year 2024 has been set as the date when the Tribunal will reconvene to review the overall working of the accord.

A3.3 Impact on downstream flows

A number of factors complicate the prediction of likely future patterns of flow downstream of Sardar Sarovar:

- the NWDT figures are based on the 75% dependable flow and it is not clear what proportion of flow will be abstracted for consumptive use in years when flow exceeds this figure;
- the rate of development of upstream reservoir storage and irrigated land both in Gujarat and Madhya Pradesh may vary from the rates previously anticipated, as mentioned above; and
- the individual states may at some future date decide to forego a proportion of the water allocated to them for irrigation and use it instead for power generation.

Nevertheless using the Tribunal's framework for water allocation and plausible assumptions about project implementation rates and operating rules, a number of operational models were developed to study the benefits obtainable from the Sardar Sarovar Projects under a range of future scenarios, see ORG (1983a),

Table A3.2 Allocation of water by Narmada Waters Disputes Tribunal

		Stage 1	Stage 2	Stage 3
Period from start of construction	Years	10	30	45
Madhya Pradesh (upstream)	$10^9 m^3$	7.4	16.0	22.5
Maharashtra (upstream)	$10^9 m^3$	0.3	0.3	0.3
Gajarat (via main canal)	$10^9 m^3$	3.1	11.1	11.1
Rajasthan (via main canal)	$10^9 m^3$	0.6	0.6	0.6
Available for power generation at SSP	$10^9 m^3$	23.1	6.5	0
Total	$10^9 m^3$	34.5	34.5	34.5

Note: Figures based on assessment of 75% dependable flow

ORG (1983b), ORG (1984), IIM (1983), and IIM (1985). The Central Electricity Authority (CEA) also undertook a simulation but a copy of their report was not available for the consultants to study. The results of these independent studies are in broad agreement with each other. Their purpose was for planning and economic evaluation rather than the optimisation of particular benefits or the study of environmental impacts but their output gives a reasonable set of scenarios on which to base predictions about downstream flow conditions. The main sources used in the following discussion are the reports of ORG.

ORG provides standard scenarios relating to Stages 1, 2 and 3 of the NWDT decision. In addition several other scenarios are investigated of which two are of particular interest here:

- Stage I (mod) assumes that Gujarat may develop its irrigation at a faster rate than anticipated. In this scenario, ORG increases Gujarat's consumptive use to the maximum allowed to it ($11.1x10^9m^3$) while keeping the use by other states unchanged;

- Stage I (delayed NSP) uses the original consumptive requirements for Stage I but assumes that the Narmada Sagar Project upstream may not be completed as fast as envisaged thus reducing the capacity to store monsoon flows for use later in the year.

Recently ORG has been commissioned by NPG to run further simulation studies extending the flow sequence by a further 12 years (to 1991/92) and considering further modifications to some of their scenarios. The results are not yet available but are unlikely to modify substantially the picture of downstream flows which has emerged to date and as described below.

The general impact on flows downstream of Sardar Sarovar is to store (or directly utilise) an increasing volume of the monsoon flow thereby reducing the downstream flow by an amount varying from $20x10^9m^3$ in Stage 1 (delayed NSP) to $35x10^9m^3$ in Stage 3. This is illustrated by the analysis of the 30 year flow sequence routed through the ORG model and shown in Figure A3.1. The figure shows the total downstream discharge for the five months June to October. (Different studies use either June or July as the start of the monsoon but since June flows are generally small in relation to the total monsoon flow the difference is not significant).

Turning to the non-monsoon flows (November to May) the total downstream discharge for the seven month period increases by as much as $10x10^9m^3$ in Stage 1 dropping back to values similar to the natural sequence in Stage 2 and then falling below these values by an average of about $2x10^9m^3$ as Stage 3 is reached, see Figure A3.2. The causes of these changes are the release of stored water for power generation in Stage 1 which gradually declines as increasing amounts of water are used by Gujarat and Madhya Pradesh for irrigation and other uses in Stages 2 and 3.

In summary, Figures A3.1 and A3.2 show that the total downstream releases from Sardar Sarovar Dam in the monsoon period will gradually decline until, as Stage 2 is reached, a significant number of years (25% at Stage 2) may have no releases during the monsoon months. In the non-monsoon period, flows in the lower river will be augmented until Stage 2 is reached after which the non-monsoon releases will steadily fall below natural flow levels.

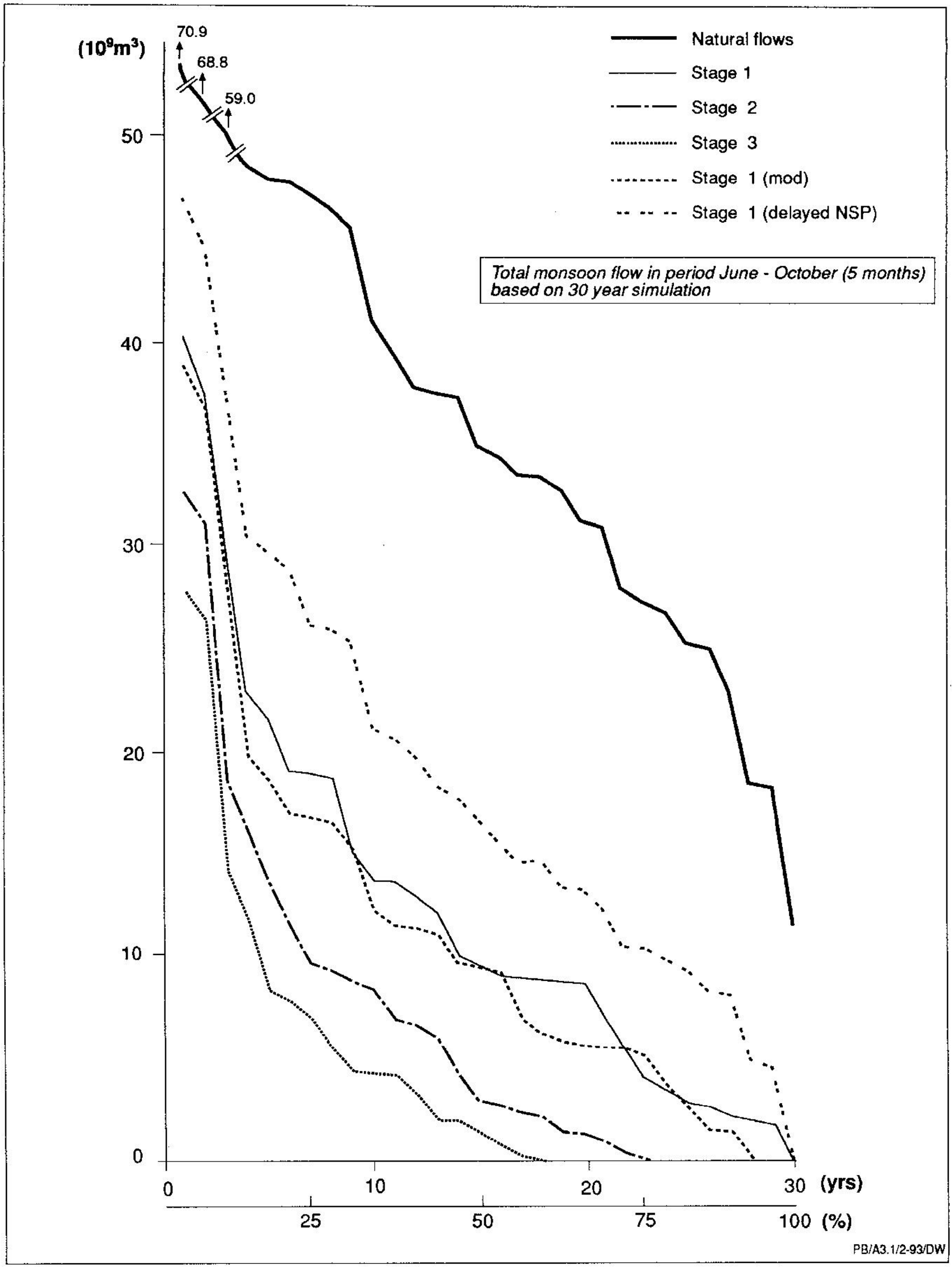

Figure A3.1 Natural and predicted monsoon flow probabilities

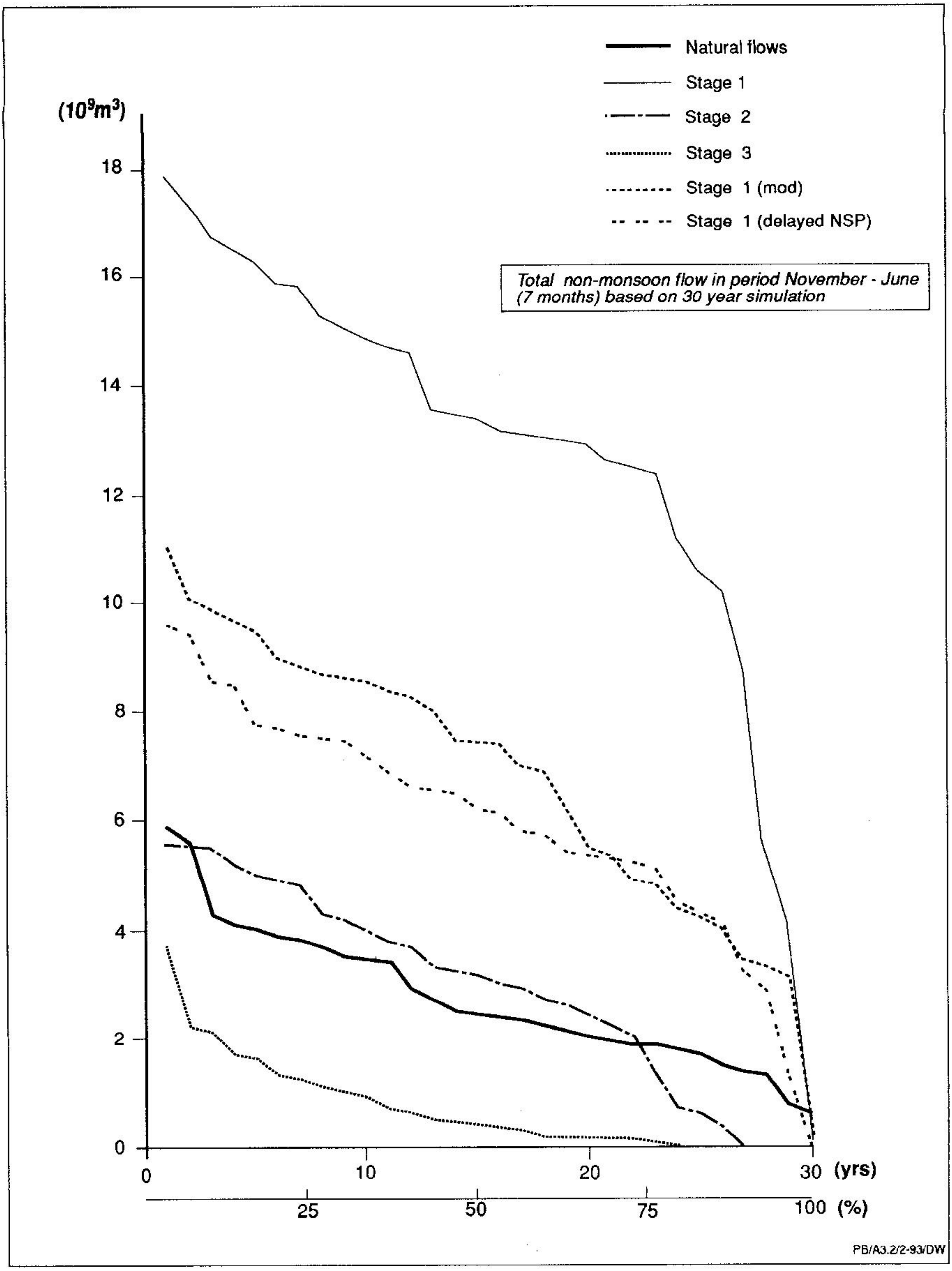

Figure A3.2 Natural and predicted non-monsoon flow probabilities

Seasonal totals by themselves are not sufficient to indicate the actual levels of flow on a monthly or weekly basis. Unfortunately ORG could not supply copies of detailed results at 10-day time-steps from their 1983 analysis having reproduced only an annual summary in the reports. However, from the limited data available and from a study of the assumptions of the model a reasonable prediction can be made about how the seasonal discharge is distributed.

During the monsoon season power releases are made at a reduced rate as the Sardar Sarovar reservoir fills and at the maximum rate possible once the reservoir level approaches the operating maximum. Hence, for much of the monsoon, particularly in the early part, downstream flows are greatly reduced but the effect on the flood peaks may be only a relatively small reduction as shown in Table A3.1. This can be further illustrated by the output for 1961/62 under the operating scenario for Stage 2, see Figure A3.3. Being taken from 10-day mean values, the flood peak in Figure A3.3 is much lower than the instantaneous peak as seen in the data of Table A3.1 for 1961. Nevertheless, the degree of attenuation resulting from the influence of the dam is of the order of 20% in both cases.

Figure A3.3 shows that in years such as 1961/62 when the peak of the monsoon occurs after the end of August, there may still be a sizeable peak monsoon flow downstream during Stage 2 although the duration of moderately high flows (say, flows over $3000m^3s^{-1}$) is reduced from 4 months to about 6 weeks in this case. However, 1961/62 was the wettest monsoon in the 30-year record. By Stage 2, ORG calculated that substantial flow over the spillway would occur in only about 30% of the years.

With regard to the flows during the non-monsoon period, a fairly accurate estimate of total available water may be made each year in November and from this an estimate of the water available for power generation during the period November to June can be made. ORG assumed that this power would be generated uniformly through the period with the result that downstream flows, especially in May and June, are generally higher after the dam than before it, even as late as Stage 2. This assumption relies on the absence of seasonal variations in energy demand and appears to be justified in relation to the recorded total demand on the electricity supply system in Gujarat from April 1991 to March 1992 (Figure A3.4): there is a relatively steady demand during the non-monsoon months compared with a fall in demand during the period June to September.

Possible daily variations in downstream discharges must also be considered. There is relatively little hydropower capacity available at present in Gujarat and Madhya Pradesh and it is, therefore, most likely that stored water will be used to meet peaks in demand rather than to provide base load. The daily load curve for Gujarat shows two peak periods, at 8am and 5pm, when the demand may increase to 20% above the mean value.

This suggests that Sardar Sarovar may indeed be used to help meet hourly peaks in power demand. However, the resulting downstream flows need not be irregular since downstream of Sardar Sarovar a weir is being constructed at Garudeshwar to store water so that Sardar Sarovar could be used as a pumped storage scheme at a later stage. This weir will have the capacity to store 6 hours of maximum turbine flow from Sardar Sarovar and has low level sluice gates through which the stored water can be released gradually throughout the remainder of the day. The Garudeshwar weir is scheduled for

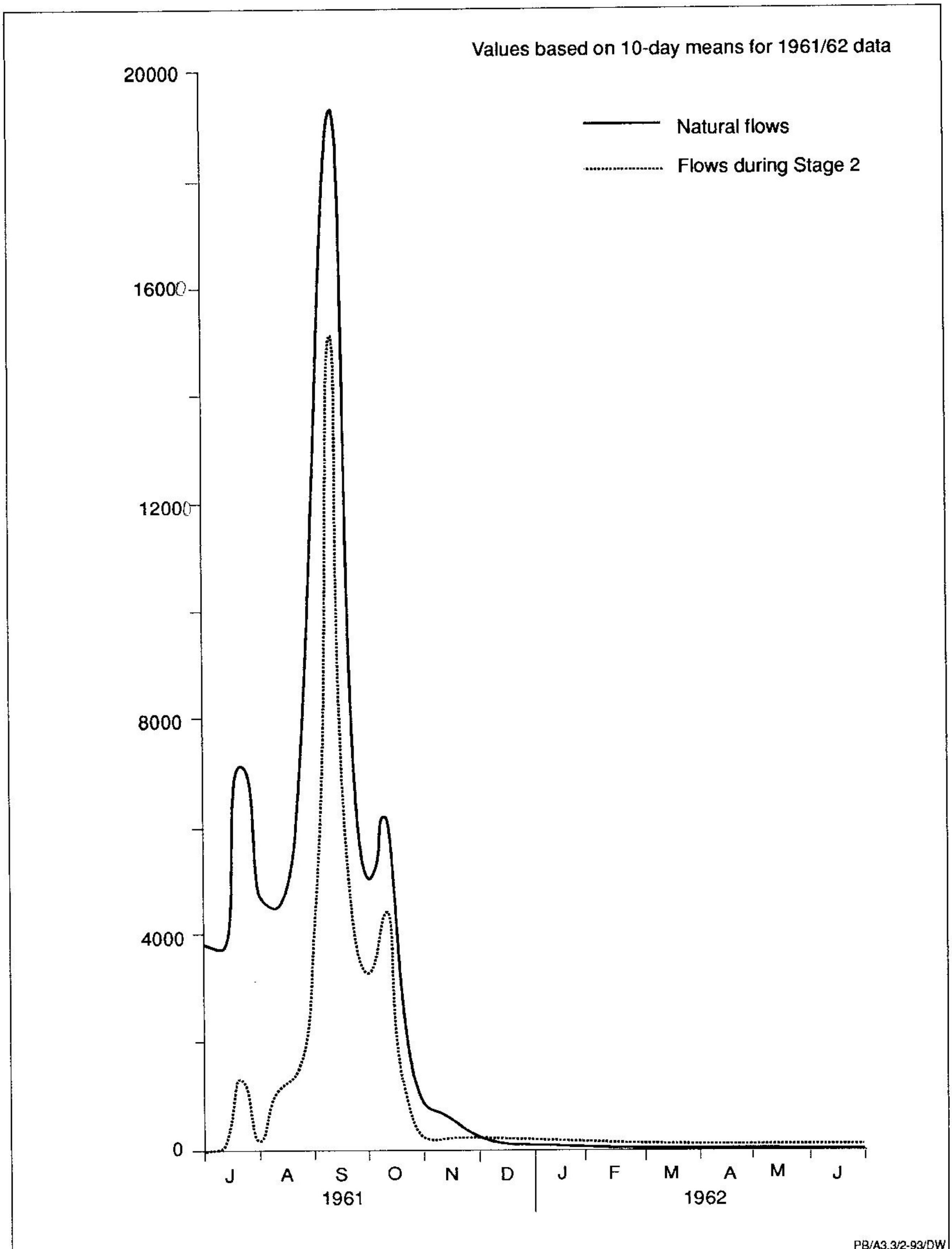

Figure A3.3 Natural and modified flows downstream of SSP

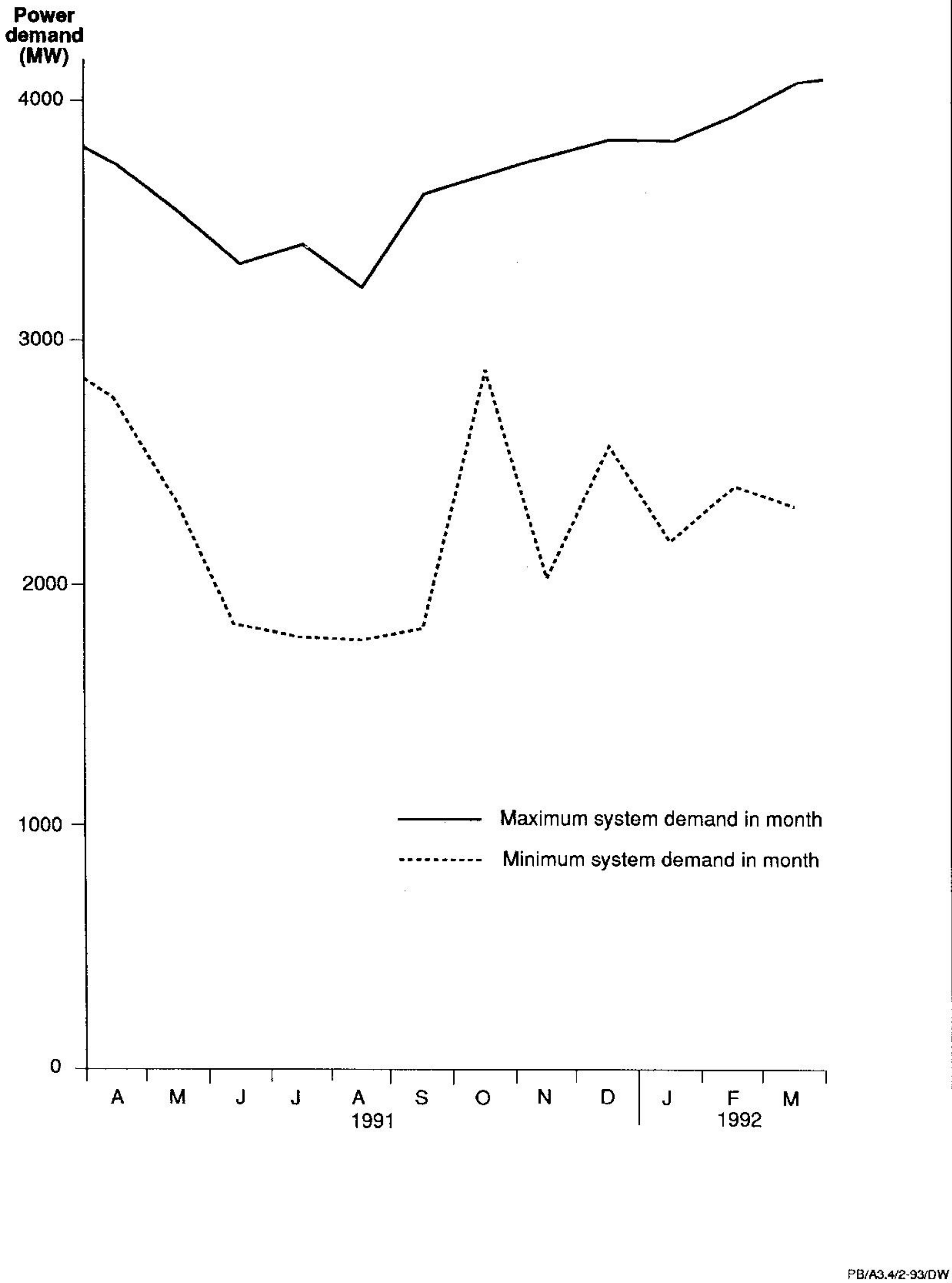

Figure A3.4 Gujarat electricity demand 1991/92

completion by 1996 or 1997. During the period before its completion, hydropower generation, will be high, most of the releases being for base load generation so daily variations in flows prior to the weir's completion should not be significant.

A3.4 Impact on flood hazard

Flood hazard in the downstream reach will undoubtedly be reduced following closure of Sardar Sarovar Dam. This is of benefit to the town of Bharuch and to the many villages along the river banks which had to be evacuated in major floods of the past such as that in September 1970 which destroyed the bridge at Garudeshwar.

There exists in the Narmada basin an established flood warning system, as in other river basins in India, whereby warnings are issued to communities at risk once river levels reach particular thresholds. In the lower Narmada the key gauging site is at Garudeshwar. The 1992 Flood Memorandum (GOG, 1992) lists 89 communities downstream of Garudeshwar which may be at risk, although some of these are on the tributary rivers. The first villages at risk are given a 'white' alert warning when the flow at Garudeshwar exceeds about $27000 m^3 s^{-1}$; a condition which occurred in approximately 1 in 2 of the years in the 30-year historical record but which, according to the figures in Table A3.1, would occur in less than 1 in 4 years in the regulated conditions of Stage 2. In reality the frequency would be considerably less than this since floods in the early part of the monsoon would be absorbed in filling the reservoir storage.

It is clear that although flood hazard is reduced by SSP, there remains a finite risk of flooding over a substantial area. The hydrological network is being strengthened to facilitate the regulation of the Narmada basin (NCA, 1989) and this provides the opportunity to give more reliable advanced warnings to communities at risk. On the other hand, if a series of dry years occurs with virtually no monsoonal spills from the Sardar Sarovar Dam, people may be encouraged to encroach further into flood-prone regions unless prevented by the application of strict flood zoning procedures.

A3.5 Contributions from downstream tributaries

In periods when there will be no releases from Sardar Sarovar, mainly in Stages 2 and 3, the contribution of downstream tributaries to the flow in the lower Narmada will be important. Some data on their discharges was provided by SSNNL (1992) but only for a 10-year period: some gauging stations were begun as early as 1952 on these rivers.

The general picture provided by SSNNL (1992) is that during the monsoon months, total discharges of the order of $1 x 10^9 m^3$ may be expected although in very dry years, such as 1986/87, the rivers may have virtually no flow for part of the monsoon period. The Karjan Dam will also have an effect on the magnitude and distribution of monsoon flows.

It is expected that more reliable data on the monsoon flows in the lower Narmada will be available once the present study of tributary flows being undertaken by CWPRS Pune is complete.

In the non-monsoon period, the tributary flows will be made up almost entirely of regeneration water from irrigation; which is estimated at 10% of applied water. In total this amounts to about $0.1x10^9m^3$ in the non-monsoon season but on the occasions when Rabi irrigation is restricted due to lack of water the amount will be less.

A3.6 Conditions during dam closure

It is planned to close the construction sluices at Sardar Sarovar Dam during the low flow (April/May) period in either 1993 or 1994 so that concrete can be placed in the toe of the stilling basin where the sluices previously emerged. A cofferdam will protect these works from discharges through the permanent sluices once the reservoir level has risen to the sill level for these sluices (53m aMSL) but for the period between the closing of the construction sluices and the reservoir reaching 53m aMSL there will be no flow downstream. During this period tributary flows below Sardar Sarovar will also be negligible.

The anticipated time required to fill the reservoir to the 53m level depends on the rate of hydropower generation from Bargi reservoir upstream. Currently Bargi is short of water so if closure occurs in 1993 there may be no releases from Bargi at the time. The natural inflow to Sardar Sarovar is taken to be $75m^3s^{-1}$ in April/May. On its own this would fill Sardar Sarovar to a level of 53m in 39 days. If augmented by flow from one hydropower unit at Bargi (an extra $105m^3s^{-1}$) the time is reduced to 16 days. If augmented by two units the time is reduced to 10 days.

A3.7 References

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Appendix 4

The tidal, salinity and sediment regimes of the Narmada Estuary and river downstream of the dam

Appendix 4 The tidal, salinity and sediment regimes of the Narmada Estuary and river downstream of the dam

A4.1 Overview

Since a number of downstream impacts depend on the nature of hydrological, morphological and water quality changes in the lower river and estuary, the NPG has commissioned the Central Water and Power Research Station at Pune to undertake a series of numerical model studies. The results of those studies were not available when this Appendix was written.

The likely impacts on the flow, salinity and sediment regimes of the Narmada estuary and river downstream of the Sardar Sarovar Dam, as assessed below, indicate the contribution which such models can make to an improved understanding of the likely changes.

It was seen that the dam will reduce the risk of flooding but holding back too much of the monsoon flows may prevent the annual inundation of the areas thought to important fish breeding grounds. The magnitude of typical maximum peak flows to avoid flooding and minimum peak flows to ensure inundation of the fish breeding ground can be determined from studies of flood propagation in the river reach.

No evidence was found of any previous problems of unacceptable levels of salinity at the existing water supply intakes, but the quantities being taken from the river are increasing and also there could be a risk of saline contamination of the group of intakes in the area around Jhanor at some critical times during the construction of the dam and later in Stage 3. The critical magnitude of minimum low flows to prevent saline intrusion can be determined from refined computer models. Temporary water supplies may need to be planned now and the longer term freshwater requirements of the area may need to be taken into account if the saline intrusion reaches too far upstream.

It was seen that a significant proportion of the sediment load of the Narmada River would settle into the reservoir resulting in possible degradation of the river bed downstream of the dam. A longitudinal profile of the existing channel is given in Figure A4.1. Model studies can show the likely magnitude and location of future scour.

The trend towards less sediment supply from inland does not necessarily mean that the channel will become deeper in the estuary because the annual flushing of sediment from the estuary during the monsoon will also be reduced when the scheme is fully operational. That is, the balance between the landward tidal transport of marine, noncohesive (sandy) sediments and the seaward monsoon flow flushing will change. Tides will become relatively more important and some sand siltation may occur. On the other hand, even though the residual sediment load from the river will be lower than at present it will contain a higher proportion of silt (because the coarser sediments will settle out more readily in the reservoir), so bed deposits may tend to become more muddy in some places. Knowledge as to whether changes of bed sediments from sandy to muddy in nature, or vice versa, are likely to occur is necessary to assess whether the availability of food in fish feeding grounds is likely to be affected. There is very little that can be done to control these natural

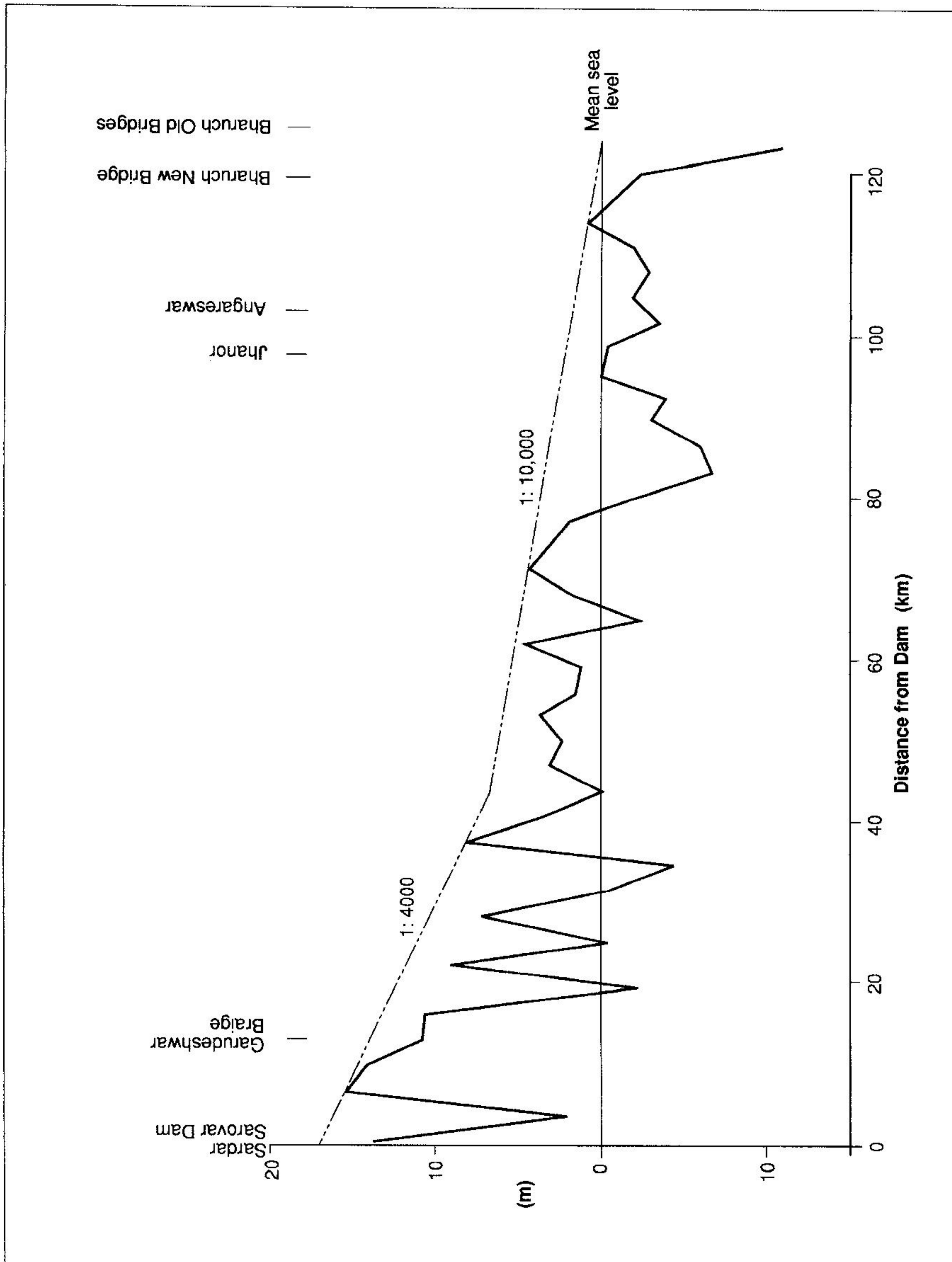

Figure A4.1 Thalweg of lower Narmada River

processes, but it is possible and advisable for the likely changes to be studied using computer models so that any adverse problems can be anticipated.

In the event that estuary depths are found to increase it will be necessary to check whether this will affect the evacuation of floods and cause associated changes to the inundation of fish breeding areas or to saline intrusion.

Another possible consequence of lower sediment loads and lower turbidity is the potential for an increase in primary production in the estuary (algal blooms) which may affect the overall ecological balance and water quality.

Lower fresh water flow from the Narmada River will reduce the flushing of contaminants from the estuary. The two main sources of pollution at the present time are industrial effluent from the Gujarat Industrial Development Corporation (GIDC) site at Ankleshwar (which discharges near Aliabet Island via Amlekari Creek) and untreated domestic effluent from Bharuch at Bharuch. In the case of the Ankleshwar discharge the dispersion of the effluent could be further hindered if significant deposition occurs in the estuary resulting in the permanent closure of the secondary channel around the south of Aliabet Island. However, neither of these sources are considered to be serious long-term problems: GIDC is undertaking to route effluent from all of the Ankleshwar industrial units through a central treatment plant to an outfall further along the estuary and a sewage treatment works is planned for Bharuch.

Two HR specialists visited the Central Water and Power Research Station (CWPRS), Pune to assess the CWPRS model studies and discuss requirements for additional work. Brief descriptions of the CWPRS models, comments on the studies and data and suggestions for further studies are summarised below.

A4.2 Summary of CWPRS models

1 Hydrology/Flood routing model

Type:	1D "Flood routing model"
Method:	Solution of St Venant Equations
Extent:	SS Dam to sea including Orsang and Karjan Tributaries

2 Degradation model

Type:	Quasi steady (constant Q_f) model
Method:	De Vries type
Extent:	Garudeshwar to Bharuch
Comments:	No armouring or sand-bed modelling Based on Englund-Hansen sediment transport law

3 Salinity intrusion model

Type:	Tide averaged/steady state	
Method:	Analytical solution	
Extent:	Upstream limit near Jhanor	
Comments:	Effective origin, Bo	] by calibration against
	Dispersion coeffs, D	] MS and 1993 data

4 Estuary models (Pilot models)

Type:	2D depth averaged models
Method:	Finite difference solutions of shallow water equations, and the equations of conservation of sand and mud.
Extent:	Bharuch (Golden Bridge) to Sea
Comments:	Grid size 420m (possibly with 140m patch in Narmada River) Idealised 4th power law sand transport.

A4.3 Summary of existing data

Estuary Model (Sea to Bharuch)

Tidal Harmonics	Bhavnager, Dahej, Ambheta	]
		]
Tidal predictions	Bhavnager	] Admiralty
	Dahej	] Tide
	Ambheta	] Tables
	Mehagem	]
	Bharuch	]

Velocity data	Hourly currents at position C on Indian Hydrographers Chart 254 for Spring and Neap tides (21°31'21"N, 72°33'18"E)
Bathymetry	Indian Chart 51 (1932) Gulf of Cambay including about 25km of Narmada Estuary (northern channel) Indian Chart 254 (1979) Gulf of Cambay only River cross-section at Bharuch
River discharges	Bharuch hourly values 1981 monsoon
Tide levels	Bharuch hourly values 1981 monsoon
Bed sediment	General identification of sandy and muddy areas. Indian charts 51 (1932) and 254 (1979) Additional bed sediment samples being collected during February 1993 at 20km spacing along the river channel and into the estuary.
Suspended loads	Typical suspended sediment concentration 25mg/l (lean flow) and 5500mg/l (monsoon flows) deduced from Garudeshwar flow and sediment discharge data for 1979

Salinity model (Sea to Jhanor)

Salinity	Salinities at various positions along the Narmada Estuary and River (MS University, 1983) Data taken from a consultant's study for Gujarat Narmada Fertiliser Company around Bharuch bridge in 1980.

Further data being collected by SSNNL over a 6-day period either side of the full moon in February 1993 at four sites along the estuary.

A4.4 Comments on Feb 1993 survey

- Dahej is not suitable for 1 year recording of sea tides due to shallow water/mud flats. Recommend installing pressure type recording tide gauge in 10m water off entrance to Narmada Estuary.

- Salinity samples should be taken at High and Low water slack (HWS and LWS) rather that at HW and LW at Dahej.

The above comments were passed onto CWPRS during the visit to Pune.

A4.5 Comments on CWPRS 2D estuary studies

HR agree that the available timescale was too short for full 2D modelling of the estuary to be undertaken by March 1993. An extensive field survey is required to enable such full 2D modelling (see Field Work specified as part of the recommended further studies).

In the interim, some early indication of the likely nature and scale of sediment related impacts can be obtained using the CWPRS pilot 2D models (tidal flow, sand and mud (silt) transport). The pilot models can be set up and run on existing data. Provisional boundary conditions can be estimated from known tidal information at Bhavnager, tidal discharges at Bharuch (ie to study tide dominated conditions) and uniform discharge at Bharuch (ie to study monsoon flow conditions). Representative suspended silt concentrations are available for low and high river flow conditions. These flow and sediment model tests will provide information on differences in sediment transporting patterns from low to high fresh water flows. In addition, the model results should give an indication whether bed sediments are likely to change from sandy to muddy nature, or vice versa, which may affect availability of food available in fish feeding grounds. The pilot models should also indicate whether the estuary would tend to deepen or silt up. In the case of estuary deepening, (and confirmation of this in subsequent full 2D model studies) the consequences on saline intrusion will need to be studied (in a subsequent tidal 1D salinity intrusion model).

The above comments were discussed with CWPRS during the visit to Pune.

A4.6 Comments on CWPRS saline intrusion model

It is considered that the CWPRS salinity model will provide good engineering predictions of salinity at various locations along the Narmada River commensurate with the timescale available for the study. In particular, by a sequence of predictions using progressively smaller and smaller fresh water flows, it will be possible to estimate critical low fresh water flow rates to ensure acceptable levels of low salinity at the freshwater intakes.

It was suggested that CWPRS should estimate the main estuary parameters (tidal ranges, tidal excursion, tidal volume, width and area exponential factors, Estuary Number) and determine the estuary type (partially or well mixed) based on the size of the Estuary Number and the Type of salinity distribution (recessive, bell or dome shape).

Knowledge of these parameters will provide insight into the relative importance of tidal mixing and freshwater flow and help identify the impacts of modified river discharges.

A4.7 Suggestions for further studies

Additional data

- Additional cross-sections for Hydrology model and new 1D Tidal model
- Bathymetry for 2D Estuary models
- Bathymetry for 2D Tarawa Island model
- Tidal data: 2 Automatic Tide Gauges + several Simultaneous Direct Reading Tide Gauges along the estuary
- 3 or 4 Recording Current Meters (RCM) for 2D Estuary model boundary conditions
- 4 or 5 Direct Reading Current Meters (DRCM) for validation of 2D estuary model and/or 2D Tarawa Island model
- Float Tracks to supplement DRCM data
- Temperature, salinities and suspended sediment concentrations at DRCM profiling positions
- Bed samples in outer estuary around Aliabet and Tarawa Islands for 2D models
- Bed samples at 1km spacing along Narmada Estuary for 2D sediment models
- Subsurface rock profile of Narmada Estuary and River downstream of Sardar Sarovar Dam (longitudinal)
- Properties of Narmada Estuary mud re-deposition, consolidation and scour in the estuary
- Wave climate (particularly SW monsoon)

Additional model studies

Improved Hydrology model

Extra Hydrology model tests

Improved degradation model

Extra degradation tests

Dynamic 1D Tidal/Salinity model
Confirmation of pilot model results, unsteady saline intrusion lag
Provision of upstream boundary conditions for the 2D models
Extra test conditions

2D Estuary model studies (Sea → Bharuch)
Flow/Sand/Mud/Poll Dispersion impact on erosion deposition patterns change in type of bed material

2D Tarawa Island model studies (Bharuch-Jhanor)
Flow/Sand/Mud/Poll Dispersion

Ideally the 2D Estuary and Tarawa models should be combined into a single model

Training and Technology Transfer

The above suggestions were discussed with CWPRS during the visit to Pune.

Appendix 5

Water Quality and Aquatic Biota

Appendix 5 Water Quality and Aquatic Biota

A5.1 Narmada river estuary

For the first 20 km below the dam site the river bed is rocky, but thereafter gives way to an alluvial reach stretching over the remaining 160 km to the Gulf of Cambay, see Figure 1. The overall gradient is slight (1:10,000) a feature conducive to upstream penetration of salt water see Figure A4.1.

More than 250 villages and towns and the city of Bharuch are situated along the river banks. The area is relatively densely populated, but largely agricultural with only limited industrial development. Consequently, pollution loads are relatively light at the present time although some of the tributary rivers exhibit significant levels of sewage pollution. Existing water uses include drinking, irrigation and various non-consumptive uses, eg fishing, bathing and livestock watering. Developing uses include hydropower and abstraction for industrial use.

A5.2 Environmental studies

A number of studies have been undertaken downstream of the dam site with regard to water quality and aquatic biota. Some are completed, others ongoing.

In 1983 the MS University of Baroda completed a six month study which described existing conditions and discussed the likely impacts of the scheme.

Since 1988 the Central Inland Capture Fisheries Research Institute (CICFRI), Barrackpore, Calcutta has conducted studies in the estuary. In addition to fisheries investigations, described in Appendix 6, these have included qualitative and quantitative assessment of planktonic and benthic communities and an assessment of water pollution.

The Central Water Commission collects samples for water quality analysis at various sites in the Narmada Basin, but the primary agency for water quality monitoring is the Gujarat Pollution Control Board, Gandhinagar. The Board is responsible for both the Global Environmental Monitoring System (GEMS) programme and the Monitoring of Indian National Aquatic Resources Systems (MINARS) project in Gujarat. They collect samples monthly from major rivers, streams and lakes in the state and at known sites of effluent outflow and also conduct a coastal monitoring programme for the survey of marine pollution. Additional marine pollution monitoring is undertaken by the National Institute of Oceanography (NIO), Goa who also conducted detailed water quality studies in the estuary in 1979.

These various organisations have generated a substantial body of baseline information on water quality and aquatic biota in the Narmada river estuary. The data is widely dispersed, however, and there does not appear to be any mechanism for coordinating studies/integrating data to ensure comprehensive coverage and uniform methodologies that address all major issues.

A5.3 Potential major impacts on water quality and Aquatic Biota

The downstream impact of Sardar Sarovar on water quality and aquatic biota will be governed by the quantum of freshwater flow, its pattern of discharge and its quality.

Details of the flow regime to be expected during the different stages of the project are described in Appendix 3. Essentially, flood flows will be substantially reduced in all stages. During Stage 1 and Stage 2 when water will be discharged through the turbines for hydropower generation minimal downstream flows will increase. In Stage 3, however, water will be retained solely for irrigation purposes. Thus, ultimately, downstream flow will diminish to a level below that of existing minimum flows.

Currently, the waters that will form the reservoir are clean and unpolluted, but water quality may be changed by impoundment. Typically, Indian reservoirs exhibit relatively high levels of productivity and deoxygenation and sulphide production is common in the lower levels of the water column.

Increased freshwater flow in Stages I and II can be expected to displace the saline wedge seawards. Indeed, construction of the Bargi reservoir has already given rise to reduced salinity levels at Tarawa by increasing minimum flow (in May) from $0.1x10^9m^3$ to $0.4x10^9m^3$, (SSNNL, 1992).

The aquatic biota would be similarly displaced with riverine communities extending further downstream at the expense of communities requiring more saline conditions. Potential weeds, such as water hyacinth, however would be less able to colonise any given reach.

The greater volumes of water available would provide greater dilution for effluent inputs although this effect could be counteracted, especially immediately downstream of the dam, if the quality of the water discharged is poor. However poor quality water is unlikely to be discharged since the powerhouse intakes are at a high level (93.7m aMSL).

In Stage 3 of the scheme the above potential impacts will be reversed due to the reduced flows prevailing. The discharge of poor quality water is unlikely in this phase, however, as releases will only occur with certain flood flows, ie from the surface layer unless a minimum river flow is maintained by discharging through the low-level sluices.

In all stages of the scheme, water flowing downstream will contain substantially less sediment due to trapping in the reservoir. Consequent changes in sediment regime downstream of the dam (Section 2.2.4) will produce changes in aquatic biota. A recent review study (GOPA, 1991) indicates that the river estuary is rich in phytoplankton and zooplankton which provide the basis for the food webs supporting commercial fisheries. Throughout winter and summer the river is coloured slightly green which is indicative of a high phytoplankton biomass. Gross primary production peaks in October/November at around 1.8 $mgC/m^3/h$ and the system is presently meso-trophic with diatoms and cyanobacteria (blue-green algae) predominant. Productivity is greatest at the river mouth due to the high nutrient content of coastal waters.

Phytoplankton growth is governed by temperature and the availability of nutrients and light. Temperature in the lower estuary is unlikely to change significantly as a result of Sardar Sarovar, but sediment associated nutrients will be largely removed from upstream sources. Development within Gujarat as a result of the dam project, however, may be expected to contribute significant additional nutrient inputs (as well as potentially toxic substances) from agro-chemical run-off and domestic and industrial waste discharge. Under these circumstances the estuary could become eutrophic. Given this scenario greater water clarity may well facilitate greater levels of primary productivity (unless inhibited by toxic discharges). Such a phenomenon could improve fisheries, but if excessive it could equally be inimical to fisheries and to other water uses.

A5.4 The role of the Pollution Control Board

Primary responsibility for the control of pollution (of air, water and land) in India rests with the Pollution Control Board of each state ; in this case the Gujarat Pollution Control Board (GPCB). The PCBs were initially established under the Water Act (1974) but wider and more centralised powers were obtained for them under the Air Act (1981) and the Environmental Protection Act (1986). Previously the GPCB set its own effluent standards related to the method of disposal but in 1991 the Government of India introduced absolute standards similar to those adopted by the European Community.

The GPCB directly monitors the effluent from existing industrial and urban sources as well as giving authorization both for the siting and treatment facilities for any new developments. In general, large industrial units have been obliged to abide by the standards required (and some have faced legal action) but the government is reluctant to press charges on smaller industrial units, especially those long-established, since the cost of effluent treatment would put many of them out of business. The GPCB has sought to overcome this problem by establishing central treatment facilities for groups of factories especially those on Gujarat Industrial Development Corporation sites. Urban (sewage) effluent is also difficult to control since the cost of providing treatment is prohibitive for certain towns. Bharuch faces this problem. In general, however, the GPCB is confident that the pollution of water bodies can be controlled under its existing powers.

GPCB also maintains a network of water monitoring stations as noted in Section A5.2 participating in wider networks both Indian and globally.

A5.5 Management options and recommendations for further studies

The preceding section on potential impacts is, of necessity, speculative as without a means of integrating the complex, interacting physical, chemical and biological processes governing water quality and the aquatic biota it is not possible to make a quantitative evaluation of the potential impacts described. Consequently, it is not possible to evaluate the effectiveness of different management options although a number are available to address the issues raised, (eg the use of appropriate operational procedures to optimise downstream discharge, treatment of effluents and implementation of water quality standards to minimise pollution). Mathematical modelling techniques offer a means of integration and could provide a useful tool for the analysis of impacts and management options. Any modelling system employed would need to address the full range of physical, chemical and biological interactions. This would have to include fully interactive sub-models for the simulation and prediction of water flow, sediment transport, water quality and biology (essentially algal growth dynamics). Such systems exist and have been successfully applied in comparable situations worldwide. Indeed, a study to investigate the Sardar Sarovar project on flow, salinity and sediment transport in the Narmada river estuary is already being undertaken by the Central Water and Power Research Station (CWPRS), using one and/or two dimensional mathematical modelling techniques, see Appendix 4.

The output from this modelling study in terms of predicted patterns of flow and physical transport could be used to drive matching models of water quality and algal growth dynamics given information on existing/projected levels of the parameters governing these processes. Much of the required data is already available from the completed and ongoing studies described above.

It is recommended that consideration be given to such an approach to facilitate the simulation and prediction of likely impacts for a range of different scenarios in order to quantitatively evaluate their extent and significance and to investigate the effect of different management/mitigation measures.

A5.6 Recommended minimum levels of monitoring

Water quality monitoring should continue on a monthly basis at up to eight sampling stations. For true comparability this sampling should be synoptic and, in those regions of the river subject to tidal influence, occur at the same phase of the tidal cycle each month.

Ideally measurements should be taken in-situ in the centre of the channel at near-surface, mid-depth and near-bed using a rapid-drop profiler possessing sensors able to measure temperature, salinity, dissolved oxygen and turbidity. Water samples should also be collected at each depth for the laboratory determination of other basin parameters such as 5 day Biological Oxygen Demand (BOD_5) Ammonia, Nitrate, Phosphate and Suspended Solids content.

Biota sampling should be conducted at least twice yearly at the times of minimum and maximum abundance to establish the range of seasonal variation in this parameter.

A5.7 Conclusions

- A substantial body of baseline information on water quality and aquatic biota in the Narmada river estuary exists.

- Currently, however, the data seems to be dispersed amongst several different agencies.

- There does not appear to be a central mechanism for coordinating studies and integrating data to ensure that comprehensive coverage is achieved, uniform methodologies are employed and all relevant issues are addressed in the most cost effective manner.

- The downstream impact of Sardar Sarovar on water quality and aquatic biota will depend on the quantum of freshwater flow, its pattern of discharge and its quality. As yet these parameters are not precisely defined.

- Comment on potential impacts at the present time is of necessity speculative as there is no mechanism for integrating the complex array of interacting physical, chemical and biological processes governing water quality and the aquatic biota.

- Mathematical modelling techniques offer the most powerful tool for achieving integration.

- A modelling study to investigate the effects of Sardar Sarovar on water flow, salinity and sediment transport is in progress.

- It is recommended that consideration be given to additionally modelling water quality and biological processes (viz, algal growth dynamics).

- A fully integrated modelling approach would greatly advance basic knowledge and understanding of the Narmada system and facilitate simulation and prediction of the likely impact(s) of different operational scenarios and the investigation of various management/mitigation options.

- In the meantime a minimum level of monitoring should be maintained with the data needs for future modelling being considered in the choice of relevant parameters and frequencies.

A5.8 References

1 GOPA Consultants (1991). Narmada River Basin Development Project. Fisheries Component, May 1991. Hindenburging 18, Germany.

2 Sardar Sarovar Narmada Nigam Limited (1992). An Approach Paper on the Environmental Impact Assessment for the River Reach Downstream of Sardar Sarovar Dam. Gandhinagar, May 1992.

Appendix 6

Impact on the downstream Narmada River and estuary fisheries

Appendix 6 Impact on the downstream Narmada River and estuary fisheries

A6.1 General

The Sardar Sarovar Dam, associated power generation facilities and irrigation command area developments, are now at a fairly advanced stage of construction, although the first phase of building work is expected to continue until about 1998. Thereafter, commissioning and operation of completed parts of the complex and further construction work is intended to proceed through three stages.

Pre-project average flows downstream of the dam site during a "normal" year, are reported to have been about 28.7 million acre feet (MAF) during the July to October monsoon season and 2.7 MAF during the November to June dry season, a total of 31.4 MAF per year (SSNNL, 1992). It is inevitable that the project will progressively alter this pattern of river water flows and that this will affect the downstream fisheries as the timing of floods and fish spawning seasons become increasingly unsynchronised.

For several years past there has been controversy about the prospective environmental cost of the project, versus the widespread agricultural and other benefits it is expected to generate in much of northern and central Gujarat. Upstream of the dam site the Sardar Sarovar reservoir and other impoundments further upriver, should produce greater volumes of more valuable fish than the pre-project river alone. However, the fish stocks and fishing communities located along the lower Narmada below the dam site are among those likely to suffer the worst disbenefits from the project in the longer term. Measures will therefore be needed to mitigate these negative impacts and a range of possible measures have been identified.

A6.2 Operation of the Sardar Sarovar Dam

(a) Initial Construction Phase

The NWDT assumed that the initial construction programme would be completed within 10 years, so that Stage 1 of the operational plan will extend from Year 10 to Year 30, Stage 2 from Year 30 to Year 45 and Stage 3 from Year 45 thereafter. In reality the timing of these stages may vary. A comparison of pre-project flows and average downstream flows to be expected during the three stages, is shown in Table A6.1 below. For further details see Appendix 3.

Table A6.1 Future downstream flows in Lower Narmada River, as percentage of pre-project average flows in normal year

	Stage 1	Stage 2	Stage 3
Monsoon	25%	8%	3%
Dry Season	405%	157%	4%
Total	58%	21%	3%

(Source: SSNNL, 1992, Annex 5)

(b) Stage 1

It is intended that early monsoon floodwaters from upstream will be retained to replenish reservoir levels, for release during the subsequent dry season, in order that the river bed power station can operate throughout the year. Average monthly release volumes derived from pre-project flows and Table A6.1 figures, for pre-project and Stage 1, are shown in Table A6.2.

Table A6.2 Average Monthly Release Flows (in MAF)

	Pre-project	Stage 1
Monsoon (July/October)	6.98	1.59
Dry Season (Nov/June)	0.33	1.35

It is not anticipated that the monsoon flows will be uniform, see Appendix 3, although a reduction in the period and intensity of the peak flows and a delayed start to the monsoon will occur. It may be possible to release greater volumes during the latter part of the monsoon season, in order to simulate a spate. However this would have to be at the cost of further reducing the earlier monsoon releases, or even blocking them altogether.

(c) Stage 2

The river power station would operate only intermittently during the second stage due to increased use of water for irrigation. In consequence, releases of water from the dam to the Lower Narmada during the monsoon season will be further reduced to only 8% of pre-project flows in an average year. Dry season releases, although less than in Stage 1, will still be nearly 55% greater than pre-project. Average monthly releases during the monsoon period would be 0.34 MAF and 0.51 MAF during the dry season.

(d) Stage 3

It is anticipated that after Year 45 there will be virtually no downstream releases from Sardar Sarovar Dam in an average year because all the available water would be diverted and absorbed into the various irrigation, domestic water supply and other projects within the command area in Gujarat and upstream in Maharashtra and Madhiya Pradesh states. The only contributions to downstream river flow will be discharges from the small tributaries and drainage from adjacent irrigation, urban and industrial areas which is liable to be polluted.

A6.3 Impacts of the project on downstream fisheries

(a) Initial construction phase

Any interference with river flow or water quality that may have occurred during the construction phase does not so far appear to have affected fish stocks or production. Most of the fish landed in Bharuch District is caught in the Narmada river and estuary. Table A6.3 shows that catches have remained stable until 1990/91 when there was a considerable increase, especially in the catch of Hilsa. This was said to be the result of a major increase in fishing effort, caused by an influx of large numbers of South Gujarat fishermen with about 200 boats during the Hilsa season. Similar but much smaller visitations have occurred in the past, and it is considered unlikely that this sharp increase in effort and catch has any direct connection with the dam development. The figures also suggest that there has been no over-fishing hitherto.

Table A6.3 Fish production in Bharuch District (metric tons)

	86/87	87/88	88/89	89/90	90/91
Cultured fish	7	24	26	30	11
Inland fish	3228	3390	3761	3797	11703
Estuaries	8602	9175	7388	10158	17066
Total inland fish	11837	12589	11175	13985	28780
Marine fish	1427	1879	1912	2114	2111
Overall total	13264	14468	13087	16099	30891

(Source: GDF, 1993)

Assigning monetary value to the catch is difficult: GDF publications concentrate almost entirely on production figures. Approximate prices paid to fishermen were collected during field visits in February 1993: hilsa, Rs 40/kg; prawn Rs 100/kg; other, Rs 15/kg. Assuming in 1990/91 that 40% of the catch was hilsa and 8% prawn, the total value of this catch is slightly less than Rs 100 crore (US $33 million). In previous years the value at 1993 prices would have been around US $15 million.

(b) Stage 1

On the basis of the data in Tables A6.1 and A6.2, there is a widely held view among the authorities concerned that State 1 flows will be more than sufficient to meet the needs of migratory fish and shellfish species, such as Hilsa and Macrobrachium. Current lack of information on fish ecology does not permit accurate predictions to be made about how changes to the pattern and timing of flood flows will affect the spawning and migration of fish such as Hilsa and whether they will be able to adapt.

In contrast to the command area, where the project will create opportunities for developing and intensifying fish farming, and to the upstream areas with their new reservoir fisheries, the prospects for the downstream fisheries appear uncertain and, as flows are further modified with time, possibly rather gloomy. The only slight cause for hope is that the enhanced dry season flows may benefit a second, but hitherto relatively minor spawning run by part of the Hilsa stock, which occurs during February and March. It also seems possible that the giant freshwater prawn, Macrobrachium rosenbergii, may be able to survive and continue to reproduce in the downstream sector during Stage 1. However if any part of that stock was able previously to penetrate further upriver above the dam site, it will become isolated and soon die out, according to experience with stocks of similar fish, especially in Bangladesh and West Bengal.

(c) Stage 2

The reduction of monsoon season flows to only 8% of the pre-project average, must mean that the principal Hilsa spawning run during July and August is likely to cease, whereas the secondary run in February/March may still continue. The effect of such changes on the overall size of Hilsa stocks and on catch rates is not known, but common-sense suggests that they are likely to be greatly reduced. The impact on stocks of Macrobrachium in the downstream river is also unknown and conjectural, but it may be possible to maintain catches by releasing hatchery produced Macrobrachium juveniles into the river.

(d) Stage 3

To all intents, the river upstream of the tidal limit will become a series of rainfed, seasonal pools for much of the year which would have to be stocked each year with hatchery produced fish fingerlings and juvenile prawns, in order to yield a crop. No further Hilsa spawning would be possible in the Narmada River. Below the tidal limit the river would effectively become a tidal, sea-water creek producing a relatively small quantity of seafish. Even that catch could depend on the effectiveness of anti-pollution measures from the urban and industrial centres around Bharuch.

Income from current fishing activities would be severely depleted by Stage 3. Losses of the order of 75% of current income (US $25 million in the plentiful 1990/91 catch) are probable, but GFD predicts that these will be more than offset by a major increase in culture fisheries in the command area.

A6.4 Summary of available studies and data

The Gujarat Department of Fisheries (GDF), Ahmedabad, in association with the Narmada Planning Group (NPG), produced several project papers (1986, 1991a, 1991b) which contain mainly proposals for the fishery components of the Sardar Sarovar programme, along with descriptions and costings. GDF also publishes annual fish catch statistical bulletins, by type of fishery, eg marine or inland capture fishery, fish farming, etc., by districts and by principal species or species groups. These tables provide valuable indications of trends in the yield and state of fish stocks. In addition, GDF has produced "A Note on Hilsa (Tenualosa ilisha) and the Giant Freshwater Prawn (Macrobrachium rosenbergii)" in 1993, which reviews current knowledge of the Indian west coast stocks of these fish. The paper draws heavily on research findings from extensive studies of the Bay of Bengal stocks.

Although less extensive a number of earlier studies of Narmada fisheries are relevant many of which were undertaken when the Central Inland Fisheries Research Institute (later CICFRI) had a field station at Hoshangabad in Madhya Pradesh. Studies relevant to the lower Narmada include Kulkarni (1951) and Karamchandani et al (1967). The latter gives detailed information on fish species, commercial fisheries and numbers of fishermen at that time.

G O Parikh's 1986 "Techno-Socio-Economic Conditions of Fishermen in Gujarat", covers inland and marine fishing households throughout the state. There is no specific reference to Narmada valley communities but the study provides an excellent insight into the lives of fishermen and their families.

The MS University of Baroda reported in July 1983 on their ecological and environmental base-line studies in the Narmada valley. The report contains very useful species checklists, fish production data and a comparison of the Narmada river with the Tapi and Mahi rivers and dams, with an assessment of likely impacts on the Narmada based on that experience. The University is also about to undertake a bench-mark environmental impact assessment study of fisheries in and adjacent to the command area of the Sardar Sarovar Narmada Project, and has just tabled a preliminary inception report on this work, which contains some useful additional information.

The German consultancy firm, GOPA, in its May 1991 "Assessment of Narmada Basin Developments", was concerned mainly with developments and impacts upstream of the Sardar Sarovar dam and did not have much to say about the Lower Narmada.

The Central Inland Capture Fisheries Research Institute has its headquarters in Barrackpore and a temporary field station in Baroda. CICFRI has been undertaking a study of west coast estuary fisheries, including the Narmada, for the past five years. The work is due for completion in 1993 and when the reporting is complete it will certainly contribute to the background understanding of the water quality, hydrology and limnology of the Lower Narmada. The work was intended to include assessment of the fish resources, analysis of fish yields and fishing effort statistics, population dynamics and biological studies of commercially important species, especially Hilsa and the artificial propagation of Hilsa. So far the annual reports have concentrated on water analyses, qualitative lists of species and trials for artificially spawning Hilsa.

The SSNNL prepared an approach study of the downstream impacts of the Sardar Sarovar Narmada Project in May 1992, which provides a good description of the downstream river and riverside population. It also details the proposed modes of operation and water release patterns together with an assessment of probable physical changes to the river bed and estuarine configuration.

Of two reports commissioned by the World Bank, the "Overview and Environmental Assessment" by D W Levenhagen, dated March 1989, provides a useful review of the then situation, but some of the claims in the fisheries section (F) needs to be read with some caution. The second document, Morse et al (1992) does not contribute greatly to the sum of knowledge about the riverine environment along the Lower Narmada, but it does flag some points of concern for the future, especially in respect of river flows, water quality, changes in salinity and consequent changes in composition and size of the fish stocks.

Additional views and comments were obtained during discussions with GDF headquarters and field staff from Baroda and Bharuch, with CICFRI and University scientists from Baroda, several groups of Narmada river fishermen and NPG experts.

A6.5 Options for mitigation

(a) Mitigating impacts on the fish stocks

In the early years of Stage 1 it cannot be ruled out that natural stocks may start to dwindle because of their inability to adapt to the altered river flooding regime. Even so, it should still be possible to maintain a reasonable level of fish production from the river, if necessary by means of annual restocking with hatchery produced carp fingerlings and juvenile Macrobrachium to supplement the residual natural fishery. The proposals to establish additional hatcheries in the Lower Narmada valley are therefore fully supported.

Later on, when water releases from the dam become too irregular, water quality in the remaining pools will deteriorate, erstwhile freshwater or slightly brackish sections will become more strongly saline and there would be little point in continuing the annual restocking programme. However, the hatcheries would still have a useful role in supplying fish fry and fingerlings to the fish farming industry which can be expected to develop throughout the command area.

Project documentation contains several references to trials by CICFRI and GDF on artificial "in vitro" fertilisation and hatching of Hilsa ova and the establishment of a breeding population of these fish in the Ukai reservoir on the Tapi river. If true this could be a valuable development well worth further investigation. However, since spawn are currently obtained by milking adults caught in the estuary prior to migration the sustainability of the breeding programme once migration ceases will have to be studied.

(b) Mitigation of impacts on the fishing communities

Karamchandani et al (1967) reported 26 321 active fishermen along the Narmada in Gujarat State but only 482 were considered to have fishing as their sole occupation and many fished only during very short periods. Recent data suggest a substantial increase in numbers over the subsequent 25 years.

GDF supplied survey data listing a total of 55 fishing centres along the banks of the Narmada River below the dam site in Bharuch District. The record shows a total of 2191 fishing families, and 12813 family members of whom 6529 are active fishermen. The survey also lists a total of 826 fishing boats of which at least 670, or more than 80% are worked in the tidal reaches as far upstream as Jhanor. The boats are flat-bottomed and designed to operate only in sheltered estuarine and river water.

The paper by SSNNL (1992) derived from a study by CICFRI (1991) states that there are nearly twice as many fishing villages and families (107 villages and 4187 fishing families) along the Narmada River in Bharuch District. In addition it points out that there are a further 29 villages with 561 active fishing families along the section of the north bank which is in Vadodara (Baroda) District. The differences between the two surveys may arise either from the method of survey or from the definition of which villages to include. In either case it is clearly necessary to verify and reconcile these figures to provide a definitive list on which detailed plans and costs can be worked out and on which rehabilitation activities can be focused. In general terms the following options seem feasible:

- Fishermen based between river mouth and Bharuch City; could be assisted to replace their existing boats with more sea-worthy craft so that they can operate in open waters in the Gulf of Khambhat. Preferably such craft should be sail propelled for economic operation, but also be fitted with auxiliary power for safety reasons. As an alternative, some fishermen could be assisted to engage in brackish shrimp and/or milkfish farming, on the tidal mud-flats on either bank of the Narmada estuary.

- Fishermen based between Bharuch and Sinor (60km below the dam) should be encouraged to continue fishing as long as possible but thereafter would have to be assisted and trained to adopt a different livelihood. Fishermen stated that some of them already have a secondary trade, eg as carpenters/joiners but probably would need help in organising such a business, or finance for better tools. Others could be encouraged to form fish farming groups, possibly with NGO assistance, to take over, rehabilitate and restock derelict village ponds with the benefit of a reliable source of water from the irrigation scheme. Others again, who either own or have access to suitable land within the command area, may wish to concentrate on irrigated farm production but this could also include the possibility of excavating and converting certain areas for fish farming.

- Fishermen based above Sinor to the Dam site have the same range of options as those in the reach from Bharuch to Sinor. In addition, however, GDF has suggested that they could be offered the possibility of being relocated to suitable sites on the shore of the new reservoir to carry on fishing there. Some additional assistance would be needed, for example, some nets needed for reservoir fishing will differ from those used to fish in the river and new marketing arrangements will be necessary. Doubts arise as to the advisability of this measure given the fact that displaced people from the reservoir impoundment zone are being moved out of that locality and it would seem preferable to retrain them to exploit any fishing opportunities which the new reservoir offers rather than replace them with fishermen from elsewhere.

A6.6 Requirements for monitoring

Despite all the work that has already been done, from the reports seen by the consultants, there is insufficient information available about the fish ecology and resources of the Lower Narmada to be able to forecast what changes will happen to the fisheries, and when, with any confidence or precision. The baseline studies already carried out by CICFRI and Baroda University leave several important questions unanswered, particularly as regards the most important fish species. For example, the Narmada River is said to be one of the only two important Hilsa spawning areas on the Indian west coast. The other, the Tapi, is already affected by the Ukai Dam. Would a Hilsa collapse not only affect river fishermen but also have a significant effect on the earnings of fishermen in coastal and marine waters where hilsa spend a large part of their life-cycle? In the Bay of Bengal, as many or more Hilsa are caught at sea as in the rivers. The mechanisms which trigger Hilsa into migrating up the rivers are still not properly understood. The monsoon flood may be a factor in the July/August migration, but what causes the February migration? What flow conditions are required to ensure that Hilsa can successfully use their main breeding grounds which are known to be located between Jhanor and Garudeshwar? Some of these questions may have been addressed in a report just submitted to NCA by CICFRI which, as yet, the consultants have not seen.

It is generally recognised that the downstream fishery will inevitably be a sacrificial casualty in favour of the wider benefits of the scheme as a whole, and that some mitigatory measures to compensate fishermen whose livelihoods may be destroyed will be necessary , but it is also widely believed that the need for such measures should not arise until the end of Stage 1, ie at least 30 years hence. The findings of this current review show that, with the current state of knowledge, the possibility cannot be ruled out that events will move faster, and that the need for some mitigatory action may arise much earlier than expected. For all of these reasons it is considered that the existing baseline work must be supplemented by a monitoring exercise which should concentrate mainly on the important fish species, their biology and on those factors, such as length frequency, sex ratio and catch per unit effort which are needed to monitor fish stock status and give warning of impending change. Other topics to be addressed should include verification of the numbers and locations of fishermen and their families, fish market supply and prices, fishermen's earnings, etc.

A6.7 Conclusions

As noted above, the main conclusions are that the way ahead, so far as fisheries in the Lower Narmada are concerned, is by no means as clear as has apparently been thought hitherto. Despite the substantial volumes of water released from Sardar Sarovar Dam, the greatly altered timings may have a severe impact on fish stocks and survival, giving rise to a much earlier requirement for mitigatory provision than expected.

It is therefore strongly recommended that the fisheries situation downstream from the dam must be carefully and regularly monitored by fisheries specialists working in close cooperation with GDF and CICFRI. Monitoring costs should be a direct charge on the Sardar Sarovar project rather than through savings from either the State or Central Government recurrent budgets, so as to ensure that the specific questions relating to the dam are properly addressed.

It is noted that there are no fish conservation or regulatory measures currently in force, because stocks have remained largely underfished hitherto. The combined impacts of Sardar Sarovar and other reservoir developments on the Narmada and other rivers will cause shortages of some fish species and add to the fishing pressure on others, because of the continuing growth in human population, affluence and demand for fish. It would be a prudent measure, at this stage to review what actions may become necessary in the near future, such as minimum size rules, close seasons or limitations on numbers of fishermen to be permitted access to certain fisheries, and to make sure that any necessary legislation can be put in place to permit speedy implementation as and when need arises.

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