DAMS AND DEVELOPMENT

A NEW FRAMEWORK FOR DECISION-MAKING

THE REPORT OF THE WORLD COMMISSION ON DAMS

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Table of Contents

List of Tables

List of Figures

List of Boxes

Cumulative Impacts

Many of the major catchments in the world now contain multiple dams. Within a basin, the greater the number of dams, the greater the fragmentation of river ecosystems. An estimated 60% of the world's large river basins are highly or moderately fragmented by dams (see Figure 3.6). The magnitude of river fragmentation can be very high. In Sweden, for example, only three major rivers longer than 150 km and six minor rivers have not been affected by dams.[46]

Problems may be magnified as more large dams are added to a river system, resulting in an increased and cumulative loss of natural resources, habitat quality, environmental sustainability and ecosystem integrity.

Although seldom analysed, cumulative impacts occur when several dams are built on a single river. They affect both the physical (first-order) variables, such as flow regime and water quality, and the productivity and species composition of different rivers. The problems may be magnified as more large dams are added to a river system, resulting in an increased and cumulative loss of natural resources, habitat quality, environmental sustainability and ecosystem integrity. The cumulative impacts of interbasin water transfers can be of special concern, as this often involves the transfer of species into new watersheds.

Box 3.7 Cumulative impact of dams: the Aral Sea

The Aral Sea, fed by the Amu Darya and Syr Darya, was once the fourth largest inland body of water in the world, ranking just behind Lake Superior. It supported 24 species of fish and a fishing population of 10 000 people. A series of dams was built on the rivers to feed an immense irrigation system and grow cotton on 2.5 to 3 million hectares of new farmland. The withdrawal of water has reduced the Aral Sea to about 25% of its 1960 volume, quadrupled the salinity of the lake and wiped out the fishery. Pollutants that had formerly fed into the lake became airborne as dust, causing significant local health problems. The environmental damage caused has been estimated at $1.25 to $2.5 billion annually.

Source: Anderson, 1997, Section 1 pii, Section 6 pii.

The WCD Knowledge Base documents a number of cumulative impacts that include water quantity, water quality and species impacts. Flood regimes are clearly affected as increasing the total storage volume by adding additional dams reduces the flood flows downstream.

In Pakistan, the Tarbela Case Study reveals that only 21% of the historical dry season flow of the Indus reaches the delta; the rest is diverted for irrigation and water supply by 22 dams and barrages,. Since the Kotri barrage was commissioned in the early 1960s, the average number of days with no river flow downstream in the dry season increased from zero to 85 (the average from 1962 to 1997). Similar impacts have occurred around the Aral Sea (see Box 3.7) and in Australia where 80 years of river regulation, construction of additional storages, and diversion of water from the Murray Darling River have reduced the median flow reaching the sea to 21% of the pre-regulated flow.[47]

Water quality parameters recover only slowly when water is released from a dam. Oxygen levels may recover within a kilometre or two, while temperature changes may still exist 100 km downstream. Where the distance between dams does not allow recovery to natural levels, the biology of many hundreds of kilometres of river may be affected by a handful of dams. Examples from the WCD Case Studies include the Orange-Vaal river in South Africa, where the impacts of 24 dams may have led to 2 300 km (63%) of the river having a modified temperature regime. On the Columbia River, Grand Coulee dam receives water that is already high in total dissolved gasses as a result of upstream Canadian dams. Before the levels can recover to natural values, spill at Grand

Coulee increases them again, passing the problem further downstream.[48] Construction of a series of dams may therefore have increasing impacts on downstream ecosystems and biodiversity.

Also on the Columbia River, the cumulative impact of an additional dam on salmon migrations is significant. It is estimated that 5–14% of the adult salmon are killed at each of the eight large dams they pass while swimming up the river.[49]

What is not well researched is the change in the magnitude of the incremental response of ecosystem function and biodiversity as a river is increasingly fragmented. Thus it is not known if there is some threshold level at which the marginal impacts of the addition of one or more dams to a particular cascade of dams will begin to decline. It is therefore a case by case call whether the ecosystem impacts of further modifying a particular river may at some point be of less consequence than, for example, putting the first dam on a free-flowing river.

Anticipating and Responding to Ecosystem Impacts

Examination of efforts to counter the ecosystem impacts of large dams in the WCD Knowledge Base indicates that they have met with limited success owing to:

- the lack of attention paid to anticipating and avoiding impacts;
- the poor quality and uncertainty of predictions;
- the difficulty of coping with all impacts; and
- partial implementation and success of mitigation measures.

Anticipating and predicting ecosystem impacts

In order for ecosystem impacts to be addressed properly, they have to be understood and predicted. The Cross-Check Survey found that for the 87 projects that provided data on ecosystem impacts, almost 60% of the impacts identified were unanticipated prior to project construction, largely due to inadequate studies. While the sample size is small for some time periods, the Cross-Check also suggests that over time the trend is increasingly to anticipate impacts (see Figure 3.7). This confirms the expectation that the trend towards the use of environmental impact assessments (EIA) would result in improved identification of potential impacts (see Chapter 6 for discussion of EIAs).

Anticipating an impact is, however, not synonymous with accurately predicting the direction and magnitude of its effect on ecosystems and biodiversity. Nor does it guarantee understanding of the further impact of such changes on the livelihoods and economic welfare of affected people. While the generalised impacts of reservoir creation on terrestrial ecosystems and biodiversity are well-known, specifics,

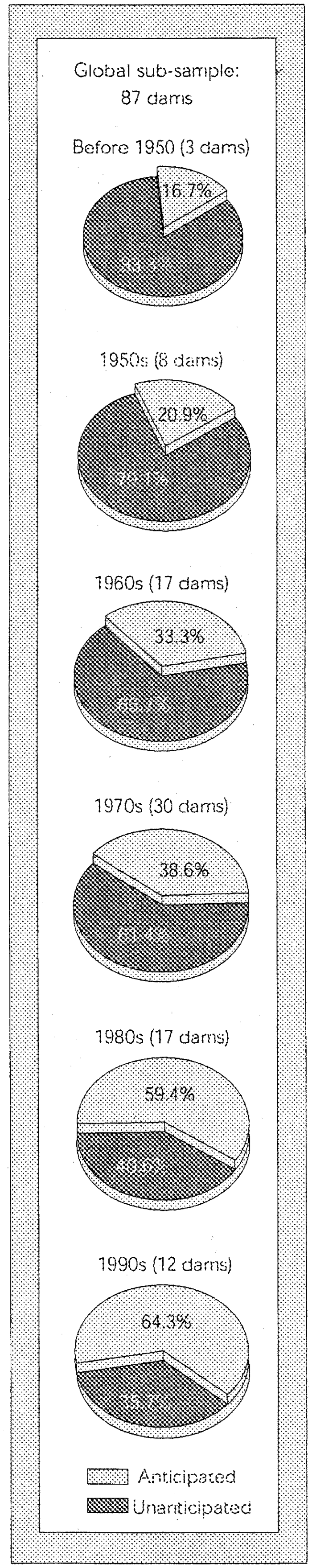

Figure 3.7 Anticipated and unanticipated ecosystem impacts

Source: WCD Cross-Check Survey.

such as the net emissions of greenhouse gases from a particular dam site, cannot be predicted with any certainty at present. Further research into the factors determining net emissions may reduce this uncertainty over time.

Downstream impacts on aquatic ecosystems and biodiversity and on floodplain ecosystems represent the sum of many complex interactions and thus are inherently difficult to predict where baseline data are absent or unreliable. However, the overall direction of the impacts is generally negative. As shown for the case of floodplain effects, the impact of large dams on these ecosystems will vary. With regard to fisheries, while it appears that the effect on species composition is generally negative at all levels (upstream, reservoir and downstream), downstream losses in productivity may be accompanied by increases in reservoir fishery production. Finally, the nature of cumulative impacts as additional dams are added to a river system may be significant, but a lack of research on the topic makes predictive assessment difficult.

Downstream impacts on aquatic ecosystems and biodiversity are inherently difficult to predict where baseline data are absent or unreliable.

In sum, past anticipation and prediction of ecosystem impacts was limited, in part due to a lack of reliable baseline data, scientific uncertainty regarding the nature of the interactions, inadequate attention paid to these issues and a correspondingly limited ability to model these complex systems. While improvements in measurement, scientific understanding and modelling capability have occurred over time, most ecosystem impacts remain site-specific. Their exact nature cannot be predicted in the absence of appropriate field studies of individual river systems.

Avoidance, minimisation, mitigation, compensation and ecosystem restoration

The WCD Knowledge Base reveals that efforts to avoid or minimise impacts through choice of alternative projects or alternative designs were more successful than efforts to manage the impacts once they were built into the design of the dam. Avoidance and minimisation of impacts, by their very nature, reduce ecosystem impacts on the site concerned. But where alternative sites or designs have been chosen, the net consequences for ecosystems have rarely been recorded.

Project planners and proponents have employed five principal measures to respond to ecosystem impacts:

- measures that avoid the anticipated adverse effects of a large dam through the selection of alternative projects;
- measures to minimise impacts by altering project design features once a dam is decided upon;
- mitigation measures that are incorporated into a new or existing dam design or operating regime in order to reduce ecosystem impacts to acceptable levels;
- measures that compensate for unavoidable residual effects by enhancing ecosystem attributes in watersheds above dams or at other sites; and
- measures to restore aspects of riverine ecosystems.

The primary option for avoiding ecosystem impacts from large dams has been not to build the dams in the first place. This is given a legal basis in Austria, Finland, France, Norway, Sweden, Switzerland, the United States and Zimbabwe, where legal 'set-aside' provisions to protect particular river segments or basins from regulation or development have been established.[50]

Good site selection, such as not building large dams on the main-stem of a river system, and better dam design also played significant roles in avoiding or minimising impacts in a number of cases in the WCD Knowledge Base.[51] The International Energy Agency also supported such policies in its recent policy paper *Hydropower and Environment.*[52] As reported earlier, an increasing number of countries are using environmental flow requirements to minimise downstream impacts (see Box 3.4) sometimes in the form of managed floods (see Box 3.6).

Mitigation was the most widely practised response to ecosystem impacts for the large dams in the WCD Knowledge Base. As noted earlier, mitigation has failed or worked only sporadically in the case of wildlife rescue operations and fish passes (Box 3.1 and Box 3.5). In the Cross-Check sub-sample of 87 projects for which ecosystem impacts were recorded, mitigation was undertaken for less than one-quarter of the anticipated ecosystem impacts (10% of all ecosystem impacts that occurred). Of these projects, 47 also recorded the effectiveness of mitigation measures implemented. Respondents stated that about 20% worked effectively, 40% did not mitigate the impact, and 40% were moderately effective. The conclusion can be drawn that only a small percentage of ecosystem impacts that occurred were actually mitigated effectively, while the relative significance of these impacts remains unknown.

While there are cases of good mitigation, the success is nevertheless contingent upon stringent conditions including:

- a good information base and competent professional staff available to formulate complex choices for decision-makers;
- an adequate legal framework and compliance mechanisms;
- a co-operative process with the design team and stakeholders;
- monitoring of feedback and evaluation of mitigation effectiveness; and
- adequate financial and institutional resources.[53]

Good site selection, such as not building large dams on the main-stem of a river system, and better dam design also played significant roles in avoiding or minimising impacts.

If any one of these conditions is absent, mitigation is unlikely to succeed. Mitigation, though often possible in principle, presents many uncertainties in field situations and is therefore at present not a credible option in all cases and all circumstances. In addition, the weaknesses of the EIA process for many projects reduces the possibility of positive outcomes.[54] This supports the use of alternative strategies rather than simply one of mitigation.

Compensation for lost resources may be 'in-kind' (for example construction of a fish hatchery for lost fish spawning areas) or 'out-of kind' (for example watershed protection in the upper catchment for loss of riverine or wetland habitat). Compensation may also be paid 'in-basin' (for example restoration of forest area within the river basin for forest lost to inundation) or 'out-of-basin' (for example assistance in expanding management capability at similar locations in another river basin). These are applied to offset ecosystem and biodiversity loss, as well as to replace lost productive use

of natural resources (as with fish hatcheries). Concerns with the effectiveness of compensation include questions about the possibility of 'replacing' ecosystem functions and species (for example, are fish raised in a hatchery equivalent to native fish stocks?) and the consequences of such efforts, for example whether fish hatcheries actually damage native fish stocks through disease and competition.

Restoring ecosystem through decommissioning

Ecosystem restoration has been undertaken in a range of countries where evolving national legislation has required higher standards of environmental performance (see Box 3.8). In the United States and France, dams have been decommissioned to restore key environmental values, often related to migratory fish (salmon), and often as a condition of project relicensing.[55]

Box 3.8 Ecosystem restoration through decommissioning in the United States

A total of 467 dams have been removed to date in the United States, 28 of these are large dams higher than 15 metres. Reasons for removal have included safety concerns, the restoration of riverine fisheries, financial considerations, or removal of unauthorised structures.

One example of a removal is the Grangeville dam on Clearwater Creek, Idaho. Built in 1903, it housed a 10-MW power plant. The removal was motivated by excessive sedimentation in the reservoir and blockage of migratory fish following the collapse of the fish pass in 1949. The dam was removed in 1963, and the river washed out the accumulated sediment within six months, with no recorded downstream effects. Removal restored access for salmon and steelhead runs to 67 km of main stem river and over 160 km of tributary habitat in the upper reaches of the Clearwater River. It also allowed members of the Nez Perce tribe to regain a traditional fishery long denied them despite the provisions of the 1855 treaty with the United States.

Source: Bowman et al, 1999, pxix, 27–31.

Ecosystem impacts of decommissioning are also complex and site-specific. One major issue in dam decommissioning is what to do with possibly polluted sediment accumulated behind the dam. The fate of this sediment when the dam is removed is frequently a major obstacle to restoration.

Current large dam designs are often not sufficiently flexible to allow for changed operating regimes to meet environmental (or other) goals. Global experience shows that these long-lived structures may be called on to operate differently in the future than in the past as society's needs and values evolve and as other dams are added in the catchment area.

In some cases, the dam design is completed before the environmental flow needs are determined, and cannot accommodate water releases of the required quantity and quality. Five dams on the Colorado River have now been retroactively fitted with variable level offtakes to draw off surface water, increase the temperature of the downstream river, and satisfy the needs of native fish.[56]

Findings and Lessons

Large dams generally have extensive impacts on rivers, watersheds and aquatic ecosystems. From the WCD Knowledge Base it is clear that large dams have led to:

- the loss of forests and wildlife habitat, the loss of species populations and the degradation of upstream catchment areas due to inundation of the reservoir area;
- emissions of greenhouse gases from reservoirs due to the rotting of vegetation and carbon inflows from the basin;
- the loss of aquatic biodiversity, upstream and downstream fisheries and the services of downstream floodplains, wetlands

and riverine estuarine and adjacent marine ecosystems;

- the creation of productive fringing wetland ecosystems with fish and waterfowl habitat opportunities in some reservoirs; and
- cumulative impacts on water quality, natural flooding, and species composition where a number of dams are sited on the same river.

The ecosystem impacts are more negative than positive and they have led, in many cases, to irreversible loss of species and ecosystems. In the Cross-Check Survey 67% of the ecosystem impacts recorded were negative. The social consequences of environmental impacts are examined in Chapter 4.

Efforts to date to mitigate the ecosystem impacts of large dams in the WCD Knowledge base have met with limited success owing to the lack of attention given to anticipating and avoiding impacts, the poor quality and uncertainty of predictions, the difficulty of coping with all impacts and the only partial implementation and success of mitigation measures. More specifically:

- it is not possible to mitigate many of the impacts of reservoir creation on terrestrial ecosystems and biodiversity, and efforts to 'rescue' wildlife have met with little sustainable success;
- the use of fish passes to mitigate the blockage of migratory fish has had little success, as the technology has often not been tailored to specific sites and species;
- good mitigation results from a good information base, early co-operation between ecologists, the dam design team and affected people, and regular monitoring and feedback on the effectiveness of mitigation measures;
- environmental flow requirements (which include managed flood releases) are increasingly used to reduce the impacts of changed streamflow regimes on aquatic, floodplain and coastal ecosystems downstream; and
- avoidance or minimisation of ecosystem impacts can be achieved through legislative or policy measures that set-aside particular river segments or basins, or through good site selection (such as avoiding main stem dams).

Finally, a number of countries, particularly the United States, are making efforts to restore ecosystem function and native fish populations by decommissioning large and small dams.