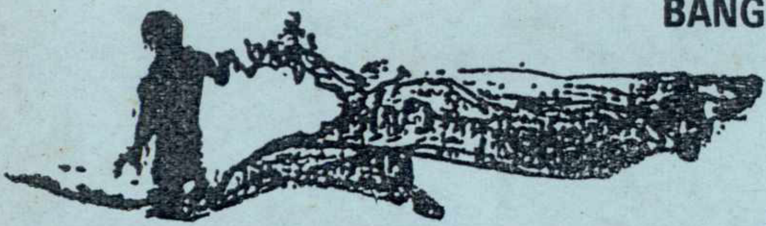

BANGLADESH FLOOD ACTION PLAN 17
Fisheries Study.

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TECHNICAL DOCUMENT: DESIGN OF "FISH FRIENDLY" REGULATORS WITHIN THE FLOOD ACTION PLAN.

JUNE 1993

Prepared for the Government of Bangladesh

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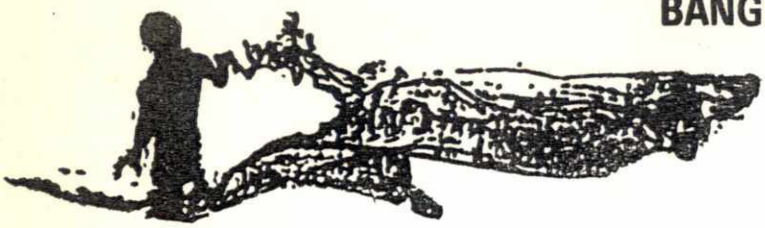

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1 Summary

1.1 A major concern when embankments are used to protect areas from extreme floods in Bangladesh is the perceived detrimental effects on the important flood-plain fisheries. There may be several reasons for this and one that has been put forward is that the gated structures (regulators) used to control the flow into the embanked areas inhibit fish movement or damage fish in passage.

1.2 Migrating adult fish, under normal flood levels, are most likely able to pass through these structures, but the distribution of fish fry being carried downstream from the spawning grounds to the flood-plains is limited and hatchlings are possibly damaged when passing through the regulators. The possible problems identified as fish fry negotiate regulators are:

1. Total obstruction to fish passage
2. Physical damage to the fish by contact with the structure
3. Damage to the swim bladder through rapid changes in pressure
4. Damage arising from turbulence downstream of the structure.

It is not considered that a normal design of regulator using vertical lift gates will completely exclude fish fry but may delay them if the gates are undershot and the gate opening is small.

1.3 Damage to fish by contact with the structure would most commonly occur at small culvert type regulator where the velocities are high and the fish are in close proximity to an extensive surface. Culverts using impact energy dissipators are unsuitable for fish passage but this type of dissipator is used where tailwater depth is low and fish movement is not likely to be high. Culvert regulators could be improved to some extent for the passage of fish by increasing the size to minimise velocities and streamlining the entry.

1.4 Damage to the fishes' swim bladder could be a serious problem and is most likely to occur with undershot gates operating at small openings. Free surface flow, as occurs with overshot gates or fully open gates, will minimise this problem.

1.5 Turbulence downstream of a regulator is not yet a proven cause of damage to fish fry in passage but clearly it is preferable if the exposure of fish fry to the often violent downstream fluctuations can be minimised.

1.6 It is considered that undershot gates are likely to provide the most convenient method of smoothly controlling the downstream level within a small range but that free surface flow is most beneficial for fish passage. It is therefore proposed that main regulation is carried out with undershot gates but that provision is made at the sides for overshot flow expressly for the benefit of fish. The unit discharge of the overshot sections would be smaller than that of the main gates and turbulence downstream would be minimised.

2 Introduction

2.1 Bangladesh lies at the meeting point of two of the world's greatest river systems. The Ganges (Padma) and the Brahmaputra (Jamuna), which meet the Meghna before running into the Bay of Bengal. The flat alluvial lands through which the rivers run form part of the flood-plain of these rivers and are susceptible to extensive seasonal flooding at high water during the monsoon season. The main flood period typically extends between July to December. Early flash floods occur in the North East region from April and May onwards. The flood waters rise until October and then recede during the dry season between November to March. Each of the three principal rivers drain different catchment areas and have different flooding patterns, adding complexity to the generalised picture for the county as a whole.

2.2 Agriculture is the dominant sector in the national economy. The country's flood-plains are intensively cultivated. Some 13 million people live on the river flood-plain in Bangladesh, the majority of which are engaged in agriculture. Crop production is possible throughout the year[1]. Production in the more secure dry season has increased rapidly in recent years with the spread of small scale irrigation from surface and ground water. Rice occupies 80 percent of the cropped area. Other important crops are jute, wheat, oilseeds, pulses, sugar cane, vegetables and spices.

2.3 There is considerable annual variation in the hydrological cycles and flooding of the rivers in Bangladesh. Settlements, infrastructures and farmers cropping patterns are well adapted to the seasonal flooding. Crops are damaged when floodwater rises earlier, more rapidly, higher or more later than the "normal" expected cycle. On occasions as much as 45% of the national land area may go under water. Such an extreme was experienced during the floods of 1987 and 1988. The consequent damage to life, property and economic production was sufficiently great to stimulate the international community to provide assistance to Bangladesh in order to prevent such extensive damage occurring in the future. One of the manifestations of this assistance has been the development of the Flood Action Plan (FAP) under the auspices of the World Bank.

Flood Action Plan

2.4 The Flood Action Plan (FAP) of the Government of Bangladesh (GoB) was developed following the disastrous flooding of the country in 1987 and 1988.The long-term aims of this plan are to provide a permanent solution to the recurrent flood problem and thereby to create an environment for sustained economic growth and social improvement. The stated objectives of the Government of Bangladesh (World Bank 1989) with respect to the FAP are to:

- safeguard lives and livelihoods;

- improve agro-ecological conditions to increase crop production;

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[1] Rice is grown in three seasons: *aus*, sown pre-monsoon, harvested in the monsoon season; *aman*, of which deep water varieties are sown pre-monsoon and short-stem varieties are transplanted in the monsoon season, both harvested after the monsoon season; and *boro*, transplanted in the dry season, harvested in the pre-monsoon season or early in the monsoon season.

- enhance development of public facilities, commerce and industry;

- minimize potential flood damage;

- create flood-free land to accommodate the increasing population; and

- meet the needs of fisheries, navigation, communications and public health.

2.5 While the need to safeguard livelihoods and reduce flood damage constituted the initial impetus for the FAP, it is also clear that, in common with major flood control measures elsewhere in the world, the major justification lies with higher economic returns from land, property and infrastructure that will result. The designed benefit of the FAP will be on agriculture, not fisheries. However, the specific inclusion of the need to safeguard fisheries among the objectives of the FAP illustrates the importance attached to the sector in Bangladesh. It also highlights the responsibility of the FAP to ensure continuing access to fish and fisheries for people living on the flood-plains of Bangladesh and to maximise the benefits accruing from fisheries as far as possible.

2.6 In physical terms, the principal objective of the Flood Action Plan is to protect large areas from uncontrolled flooding through providing structures which will control inflow and drain excess rainfall from the protected areas (World Bank 1989). The need to protect large areas from flooding would almost certainly entail the use of embankments. This has lead to the "compartment" approach proposed in the UNDP-GoB Flood Policy Study for the development of areas protected by continuous lengths of river embankments. In this approach, embankments would be built to completely enclose blocks of land, with one side of each block usually formed by a river embankment. These structures would be provided with mechanisms to control water inflow and drainage. The concept has much in common with polders which already exist in some parts of Bangladesh.

2.7 As part of a wide-ranging appraisal of flood management in Bangladesh, the British Overseas Development Administration (ODA) are funding Flood Action Plan 17 - Fisheries Studies (FAP-17). One facet of this study is the effect on fish production, particularly in the natural flood-plain fisheries, of embanking presently open flood-plains and controlling flooding with structures of various types. Based on past experiences, questions have arisen as to whether controlled flooding has an intrinsically detrimental effect on flood-plain fisheries and whether the structures themselves impede or damage fish in transit.

2.8 To moderate and offset the predicted decline in fish production from the open water fisheries, a number of mitigating measures have been proposed, including modification of the flood control structures. This report presents the findings of preliminary investigations conducted by FAP-17 as to the feasibility of so called "Fish Pass" structures.

Terms of reference of FAP -17 "Fish Pass Study" hydraulic engineer.

2.9 Assess the range of flows to be dealt with, in order to maintain adequate fish access at critical times of the year at probable flood control structure locations. Such assessments should include consideration of any seasonal migration of species, and hydraulic parameters such as the likely pattern of river flow, volumes and water levels, and the probable velocities at significant points in the river system.

2.10 Using the information so obtained, consider the likely size and disposition of the major structures required for flood control. Such consideration should include allowance for maintenance of adequate navigation.

2.11 Based on the foregoing schematic layouts, consider the alternative types of fish pass structure, which might be used, and hence recommend the most relevant, together with indicative costs and methods of operation. This section of work will require consultation with the senior fisheries scientists a the FAP-17 Office in Dhaka, and the hydraulic engineer of FAP-20, and should result in basic layout drawings of recommended fish pass structures.

3 Project Environment

Hydrology of Bangladesh rivers

3.1 Floods in Bangladesh are a complex phenomenon. An understanding of the environmental context in which floods occur is essential for identification of appropriate measures to mitigate their effects.

3.2 The Ganges has a vast discharge basin of 1.06 million km^2, extending over a distance of 2,552km and has an annual flow 468.7 billion m^3 (Griffiths 1992). It receives most of its water from headwaters draining the southern side of the Himalayan range. The Brahmaputra River has a total length of 2,900km. It drains the northern and eastern ranges of the Himalayas before running for its last 480km through Bangladesh, where it unites with both the Ganges and Meghna Rivers before discharging into the Bay of Bengal through the Meghna estuary. The major rivers and their tributaries have their headwaters outside Bangladesh; only about 7.5 per cent of their total catchment area of about 1.5 million square km lie within Bangladesh. Similarly, about 90 percent of their annual flow originates outside the country.

3.3 All three rivers have their own flood cycles; the flooding experienced in Bangladesh is a consequence of the three. The fact that the sources of the Ganges and the Brahmaputra are in the same mountain range contributes to the similarity of their flood cycle. In addition, during the monsoon season of June to September some of the highest recorded rainfall in the world occurs over Bangladesh and in the upstream catchment of the major rivers. In Bangladesh mean annual rainfall ranges from 1,200mm in the west to almost 6,000mm in the east, whilst in the Himalayas annual rainfall averages around 5,000mm (World Bank 1989).

3.4 Rainfall within Bangladesh, combined with rainfall and snow melt within the Ganges and Brahmaputra basins, produces a flood season which coincides largely with the monsoons, starting May / June. The waters diminish to dry season flows from October / November. Since rising discharge rates and water levels tend to provide the signals for upstream spawning migrations of many species of riverine fishes in the region, the period of April through to June is critical in the life cycle of fish in all rivers in the country.

3.5 Whilst the high water season is broadly similar in all three rivers, they do differ in their relative contribution. Peak discharges are of the order of 100,000m^3 sec^{-1} for the Brahmaputra, 75,000m^3 sec^{-1} for the Ganges and 20,000m^3 sec^{-1} for the Meghna. Typically there are differences in the timing of peak discharges with the Brahmaputra peaking a little before the Ganges. The exception of this was 1988 when not only did the peaks coincide but the peak discharge of both rivers was exceptionally high. It was this feature which led to the extensive and damaging flows of 1988.

Flooded areas

3.6 The *Master Plan Organisation (MPO)* of the Bangladesh Water Development Board (BWBD) estimates floodland as all land seasonally that would be flooded to a depth of 30 cm (F1 through to F4); giving a total area of 6,301,000 Ha, of which 814,000 Ha. are fully flood protected leaving 5,487,000 Ha.

3.7 Except on land close to the major rivers and on foot hill plains, seasonal flooding is mainly by rainwater ponded on land where drainage is blocked by already high river levels. Flood-plain gradients are low. Over-land drainage is often impeded by silted up old river channels, road and railway embankments lacking adequate bridges and culverts, and rice fields surrounded by bunds. Embankments can provide protection river floods but drainage systems are required to reduce rainwater flooding.

3.8 A comprehensive account of the countries physical environment is given in the FAO Agro-ecological Zones study report[2]. Relief and soil patterns are often complex. Most flood-plain villages have elevation ranges of 1m or more, with permeable loamy soils on the higher parts and impermeable clays in the lower parts. These elevation differences determine local differences in depth and duration of flooding. They also determine cropping patterns: differences in elevation of as little as 30 cm can be highly significant for crop, crop varieties and seasonal rotations in relation to flooding characteristics.

Fish in the rural diet

3.9 Fish from the freshwater capture fisheries production is a readily available food resource that is of certain major nutritional benefit to the rural poor of Bangladesh[3]. A recent household surveys conducted as part of the World Bank Third Fisheries Project have indicated that around 85% of people living on the flood-plain carry out some fishing during a year. The average fish consumption in rural Bangladesh was approximately 30 gm per capita per day in the eighties[4]. The level of dependence on fishing as a food source and income-earning activity varies during the year but peaks as the floods recede, when fish are concentrated in progressively smaller areas and thus easier to catch.

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[2] FAO, Land Resources Appraisal of Bangladesh for Agriculture Development, Report No 2 Rome, 1988.

[3] FAP-17 "Technical Document: Alternative approaches to assessing the socio-economic impacts of changes in fish production due to the Flood Action Plan."

[4] Report on the Household Expenditure Survey 1988-89; BBS 1991.

3.10 The movement of fishes with the floods, onto and over the flood-plain, ensures the access of a large part of the population to fish resources. The traditional importance of fish in the diet of the people of Bangladesh is in large part due to this movement and which makes the fisheries resources easily accessible to a wide range of the rural population.

4 Potential impacts of flood control on fisheries production.

4.1 The pattern of use of flood control structures to be developed from the Flood Action Plan has yet to be finalised. Nevertheless, it will almost certainly entail the greater use of embankments to control or partially control the encroachment of floodwater. Though the evidence is fragmentary, it is clear that flood control does have an impact on fish production from the open water fisheries by obstructing the access of riverine fish to the flood-plain; thereby restricting their opportunities for feeding and reproduction. This obstruction would also limit the numbers of fish available to households living on the flood-plain.

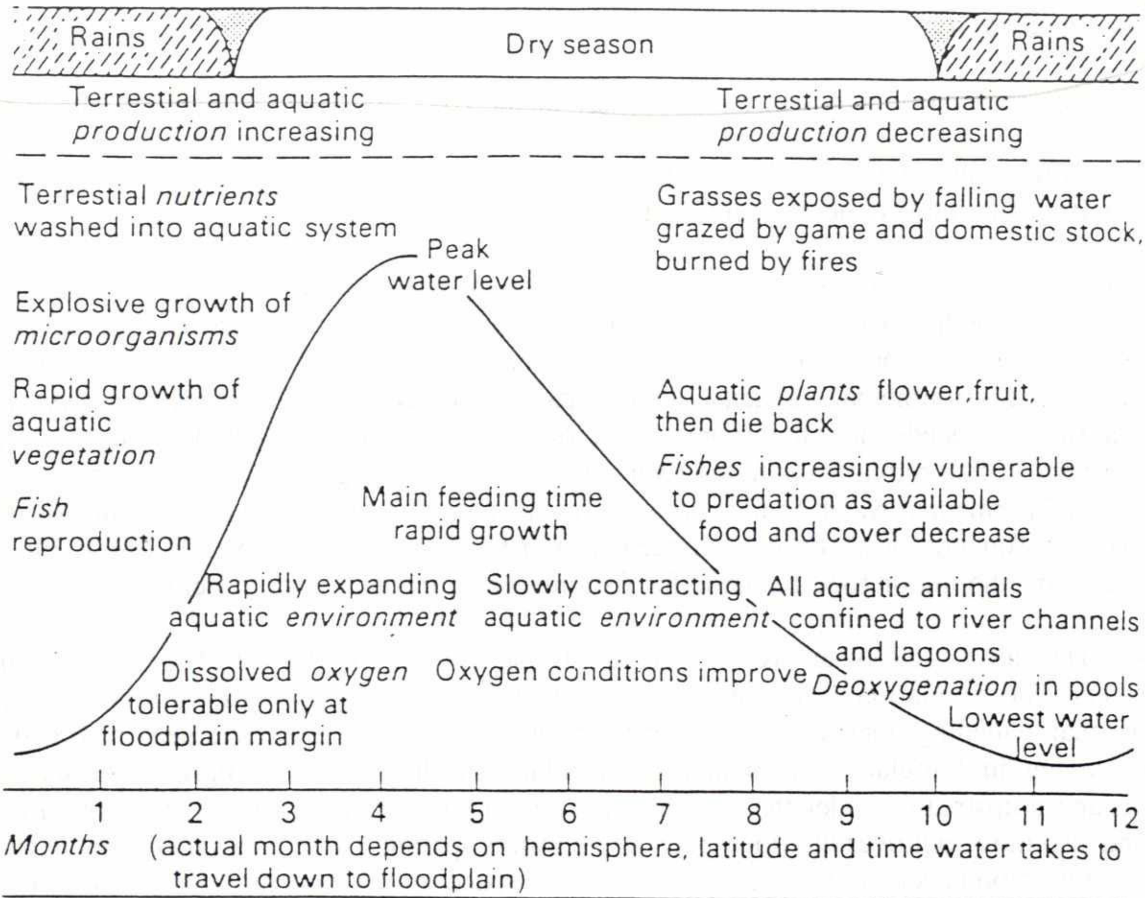
4.2 The compartment is perhaps the most extreme mechanism for controlling floodwater which is being proposed within the FAP. Other options under consideration include submersible embankments, which aim to exclude flood waters up to certain levels in order to safeguard crops at critical periods of the year. Different structures, and the way in which they are constructed and managed, will have different degrees of impact on fisheries production. Embankments of any kind will inevitably disrupt fish movement to some degree although provisions for controlled water inflow can be made to minimise the damage to fisheries resources and maintain some elements of the natural system. Some of these options are being tested by the FAP-20 Compartmentalization Pilot Project working in Tangail District.

4.3 In order to assess and quantify the true impact of FCD/I projects on fisheries production, and more importantly to assess the feasibility of various mitigation recommended to minimise negative impacts on production, it is necessary to identify the potential impact of flood control engineering interventions on the life cycle of the species contributing to fisheries production.

Fishes life cycles

4.4 A great range of niches are available within the river flood-plain complex (Figure 1), which contributes towards the characteristic great diversity and high biomass of fish present. Fish of tropical flood river systems tend to show rapid growth rates and short-life cycles compared to lake fish or temperate species.

4.5 The life cycles and behavioural patterns of fish which inhabit rivers and flood-plains that show well defined seasonal flood regimes, are closely related to changing water levels and river discharge. Large annual fluctuations in volumes of river and flood water cause seasonal shifts between predominantly aquatic and terrestrial environment. The fish and ecology are strongly influenced by the flood regime and the alternation between aquatic and terrestrial phases. Extreme oscillations, in conditions and in the distribution and availability of resources exerts a profound effect on the productivity, community dynamics, biology and behaviour of the fish. Life cycle patterns of behaviour have evolved to be synchronized



Fish movements	Up channels	Disperse on floodplain	Down channels back to river	Fish restricted to dry season refuges
Fishing activity	For upstream migrants (often illegal fishing)	Fish difficult to catch (much cover)	Intensive fishery as fish migrate	Fishing in pools and river bed
Fish biomass	Production of young by most species	Rapid growth: rapidly increasing ichthyomass	Heavy losses from predation and stranding	Much reduced populations

Figure 1 The seasonal cycle of events in a floodplain river (Lowe-McConnell 1975)

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with the cyclical nature of the flood regime that determines environmental capacity and food availability.

4.6 The seasonal changes in the hydrology of the river and flood-plain environment are probably the most important stimuli to changes in feeding and breeding activities, dispersal and movements of fishes which in turn determine diet, sexual activity, rates of growth, specific associations and oxygen requirements.

4.7 During the wet season, the over-bank spillage of floodwater from main river channels, through secondary rivers, onto the flood-plain provides important pathways for fishes to enter and migrate onto the flood-plain area. The flooded flood-plain presents a dramatic increase environmental capacity (living space) and available food resource. As the floodwaters recede and the supply of resources upon the flood-plain diminish, large numbers of fish retreat back to the rivers channels and drainage systems (khals) and to the residual permanent water bodies (beels). Growth is rapid in both juveniles and adults in the flood season but slows or is even negative during the dry season (Smith 1991). Flood-plains are the major food resource for fish inhabiting tropical river systems.

4.8 The flood cycle is an essential element in the life history of most of the fishes in the rivers. The inundation of the flood-plain provides the spawning grounds, nursery areas and the major feeding opportunities for many of the 256 species which have been recorded as occurring in Bangladesh (Rahman 1989). Many of these species migrate considerable distances upstream, under the stimulus of the rising waters, to reach the spawning areas, and also move out over the flood-plain as the waters spread. These fishes therefore, depend upon the flood cycle to provide feeding grounds, space for reproduction and also to provide environmental triggers that synchronize their life cycles to the flood cycle of the rivers. The movements of the fish populations for spawning and feeding must be co-ordinated and it is the information derived from the changing water conditions during the flood cycle, which provides the basis for their co-ordination.

Migration[5]

4.9 Few flood river fish are confined to one habitat. The species that reside on the flood-plain and beels at the height of the dry season tend to be those with adaptations to withstand limiting conditions (such as desiccation, isolation and deoxygenation in the dry season pools and are often the "blackfish" type (section 4.13) or are limnophyllic. The majority of species, are however migratory. Of these, some are restricted to a small geographical area and make only short migrations (20-30 km). Some, however, migrate substantial distances - up to several thousand kilometres between widely different habitats.

4.10 For fish inhabiting seasonal flood-plain river systems, the extreme spatial and temporal differences in the distribution of resources means that the optimum habitat for feeding rarely coincides with that for breeding. The two sites may be isolated and separated and migrations between the two are undertaken to optimise available resources. The breeding grounds are upstream of the feeding grounds (flood-plains) so that the relatively

[5] Appendix I: Classification of Migratory Fishes

immobile eggs and hatchlings can drift downstream towards the feeding grounds as the first stages of development progress. The developing fish are transported and dispersed with the floods through the secondary river systems and by the time they reach the flood plains are at a development stage able to exploit the rich food resources.

4.11 Fish migration is most commonly associated with a behavioural response to currents. The nature of this response can, however, change during the life cycle of the species. The most fundamental distinction of response is between active upstream migrations, usually of adults to their spawning grounds and the passive combined active/passive downstream migrations of juveniles. For the population to be maintained in the river, both phases need to be possible (Figure 2).

4.12 Whilst this is the basic pattern, different species of fish differ in the extent of the various responses. With regard to migratory response, the fish communities of Southern Asia have been divided into the "black fishes" which are essentially resident on the flood-plain and the "white fishes" which show some distinct migratory movement within the river system, usually associated with spawning.

4.13 The "black fish" community are those which would normally retreat into the beels or other residual water after the floods have receded. They are predominantly those species which are commonest in the kua or fish-pits, which trap the last remnants of the flood-plain waters. Anabas testudineus, Puntius, Mastacemblus, Channa, Colisa are typical of these essentially resident species. As the residual water is used ever-more intensively, the dry season habitat and refuges for these species must be diminishing.

4.14 The "white fish" community can be divided into three categories depending on the extent of migration:

i) Those with considerable longitudinal migrations which may be followed by lateral migrations onto the flood-plain (eg Pangasius, Tor);

ii) Those with limited longitudinal migrations followed by latitudinal migrations onto the flood-plain (eg major carp species, Clarias); and

iii) Those species which are truly, anadromous moving from the sea and into fresh water (eg Hilsa).

4.15 There are few direct observations on the migration of fishes in the rivers of Bangladesh. It is necessary, therefore, to infer the most probable pattern of events from observations elsewhere in the Gangetic or Brahmaputra systems or from other regions with hydrological conditions which are essentially tropical. The mahseers, such as Tor putitora, which in India do move considerable distances into headwaters streams to spawn (Talwar and Jhingran 1992), are of the first category of migratory species. It would appear that by far the greatest number of migratory species in Bangladesh exhibit category (ii) migrations; observations in India suggest that Catla (Jhingran 1968), Labeo rohita (Khan and Jhingran 1975) and Cirrhinus mrigala (Jhingran and Khan 1979) all show only local movements upstream and primarily migrate laterally onto the flood-plain after spawning along the margin adjoining the river. However, it has been suggested that the major carps carry out

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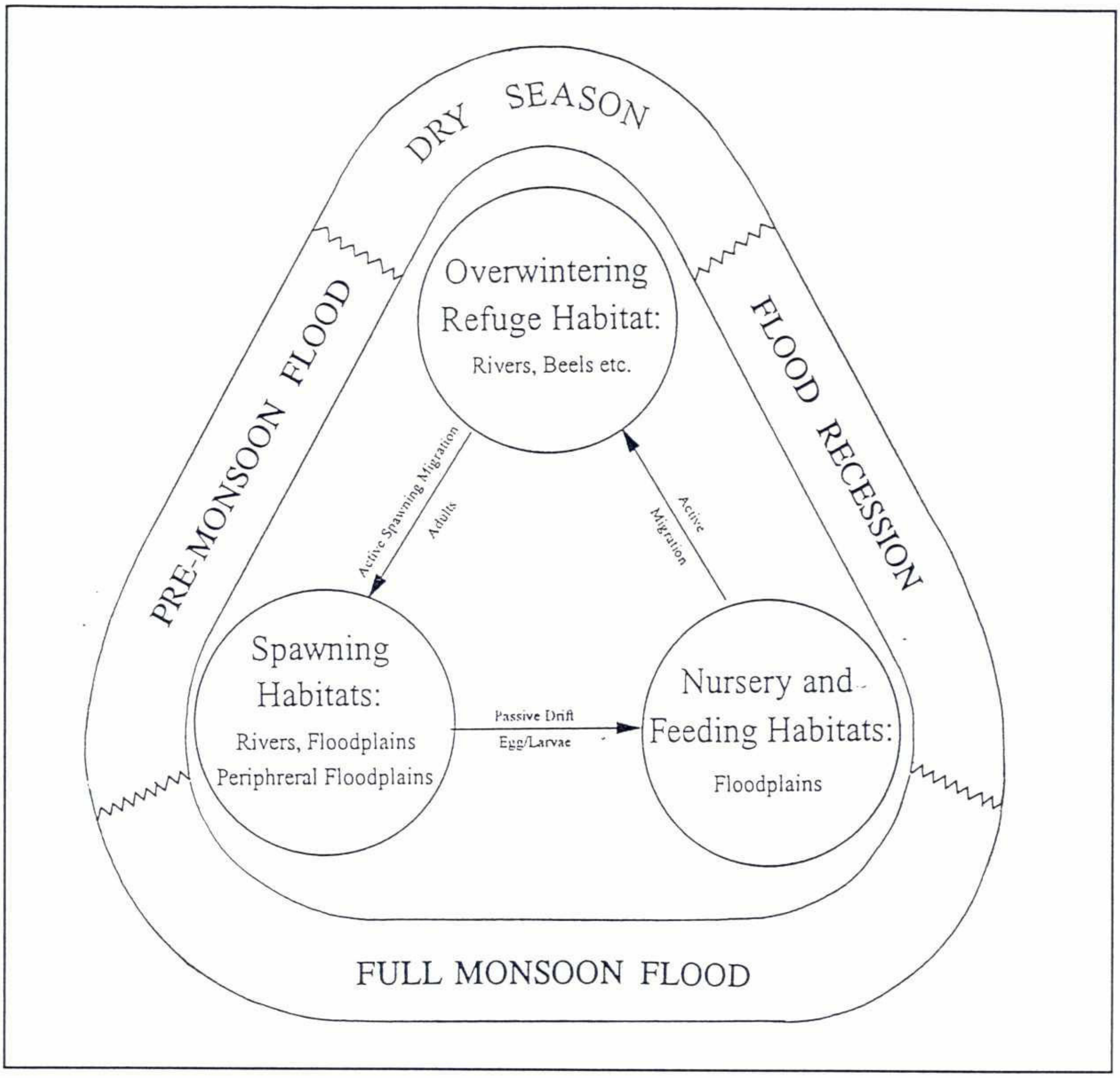

Figure 2 Basic pattern of migration between feeding, spawning and nursery habitats.

long distance migrations beyond the borders of Bangladesh to spawn (Tsai and Ali 1985), but evidence of fry catches along the banks of the Padma (Nabi and Hossain ;1982) suggest local spawning grounds given that there is little possibility for upstream migration with the presence of the Farrakah Barrage just over the border in India. It is probable that the spawn is locally produced as in the Kaptai River (Tsai and Ali 1988). The position of the catfishes in Bangladesh is least clear. In Africa many of the catfishes such as Clarias, Schilke and Eutropus show local migrations plus the lateral movement onto the flood-plain as outlined in category (ii), (Lowe McConnell 1975). The common catfish Clarias batrachus has been mentioned as migrating onto the flood-plain (Talwar and Jhingran 1992) but the position of the siluroids Ompok, Mystus and Wallagoina is unclear. Elsewhere, catfishes of this type would typically show movements of the category (ii) type.

4.16 The diadromous Hilsa shows large-scale movements from the estuary into the river during the monsoon season typical of category (iii) migration. In the Hooghly a smaller peak later in the winter has also been noted (Pillay and Rosa 1963). However, there is also the suggestion of resident river populations in the Ganges (Pillay and Rosa 1963) and Islam and Hossain (1983) have noted that small numbers are available near Rajshahi at all times of year. The breeding season occurs here in July to November and January to March (Islam and Hossain 1983).

Impacts

4.17 Table 1 identifies the possible impacts of FCD/I schemes on fisheries production as a matrix of the alteration of the hydrology of the flood-plain against the consequences for various environmental characteristics, fish behaviour and fisheries production. Reduction of flood extent will decrease the extent of the feeding grounds for fish with a consequent fall in production of the fisheries. Reduction of flood depth may increase productivity of the aquatic environment and increase the availability of nesting sites for "blackfish" species; the effect of this on overall fisheries production is uncertain but could well increase the productive potential of the residential "blackfish" species. Restriction of river bank overspill will delay the inundation of the flood which will disrupt the breeding cycles of "whitefish" species and decrease the distribution of "whitefish" hatchlings over the flood-plain. This would have a major impact on the biodiversity of the fishery, with an unknown effect on the productive potential of the fishery. In addition, restricted access to the flood-plain through channels and regulators would allow application of more efficient fishing techniques, leaving the fishery more susceptible to over fishing with a consequent fall in long-term production. Reduction of water flow through the flood control scheme willincrease the risk of pollution with a consequent degradation of land and water resources leading to a fall in production. Finally increased drainage congestion would increase the aquatic habitat but the effect on environmental capacity is uncertain given the possible impact on water quality; the effect on fisheries production is therefore uncertain.

4.18 FAP-17 recomputation of GoB FRSS statistics suggests that catch from the rivers and floods-plains that can be attributed to flood-plain production is in the order of 1 to 1.5 million metric tonnes per annum[6]. The costs to the national economy of a decline in such a readily available resource of high nutritional utility are likely to be high: these potential costs may be avoided by careful planning which takes steps to prevent the decline of the resource.

[6] This estimated production level is supported by estimates derived from household consumption data. Report on the Household Expenditure Survey 1988-99. BBS.

Table 1: FAP Fisheries Production Impact Matrix

Characteristics of existing Situation	Possible Impacts of Engineered Flood Control Mechanisms Affecting Fisheries Production				
	Reduction of flood extent.	**Reduction of flood depth.**	**Restriction of river bank overspill.**	**Reduction of water throughput.**	**Drainage congestion.**
Environmental capacity.	Reduction of flood-plain environment.		Delay of inundation of flood-plain		Uncertain.
Water quality.				Increased risk of pollution; eutrophication and deoxygenation.	Possible stagnation.
Ecosystem production.	Decrease in aquatic productivity. Loss of nutrient input for terrestrial production.	Increase in aquatic productivity.		Reduction of environmental production.	Uncertain.
Land use.	Increase in cereal production. Increase in aquaculture opportunities.	Increase in crop security.	Increase in crop security.	Degradation of land and water resources.	Waterlogging. Loss of agriculture.
Biodiversity.	Loss of aquatic and terrestrial biodiversity.		Loss of fish biodiversity; depletion of migratory species.	Loss of biodiversity.	Uncertain.
Fish migration.			Loss of migration routes and decrease in distribution of fish hatchlings over the flood-plains.	Degraded environment.	
Fish reproduction.		Possible increase for nesting sites.	Disruption of breeding cycle.	Increase in natural mortality.	
Fish growth.	Decrease in feeding grounds for fish.	Uncertain.	Loss of access to flood-plains; reduced feeding opportunities.	Degraded environment, loss of feeding opportunities.	
Fish Production.	Loss in production.	Increased production potential for "black" fish. Outcome for fisheries production uncertain.	Increased susceptibility to capture due to restricted entry to the flood-plains through regulators and channels. Long-term reduction of fisheries production.	Reduction in fisheries production.	Uncertain.
Environmental stability.	Short-term increase in stability.				
Environmental sustainability.	Possible loss in sustainability.				
Fisheries resource sustainability.	Loss in sustainability.		Increased susceptibility to overfishing.	Increased susceptibility to overfishing.	Uncertain.

5 The need for fish passes

5.1 It is possible to partially mitigate the negative impacts due to restriction of river bank overspill, through structural addition and / or modification of flood control engineering. Experience in South America and Russia shows that the use of fish passes and the employment of artificial stocking are complementary (Bonetto 1980; Poddabnyi et al 1984) and a combination of both approaches is now commonly employed in mitigation. Valuable sturgeon stocks are maintained in the Volga River by a combination of a massive rearing programme and the construction of fish passes on barriers in the lower reaches of the river (Pavlov and Vilenkin 1991; Pavlov 1989).

5.2 A number of structures, which might collectively be called fish passes or fish ladders, have been devised for circumventing engineering structures that used in water management but which obstruct fish movement. Normally these are found in association with structures that are essentially dams which cut across the main flow of the river. Where barrages may be planned that require a fish ladder for fish migrating upstream, the methodology for their design is already developed. The requirement is detailed knowledge of the physiology of the local fish concerned and the design parameters of the structure. A fish pass design is then tailored to a specific structure.

5.3 Dams and barrages are designed to maintain differences in heads of water far greater than the metre or so head differential that may result from the flood control embankment engineering in Bangladesh. There are no main river structures intended to maintain water levels above the natural level. The concept of fish ladders to enable fish, migrating against the current, to surmount permanent large variations in water level is therefore generally not applicable in Bangladesh. Nevertheless, the principles used in the design of such structures will be essentially the same as for the design of structures that will allow the movement of fish onto the flood-plain.

6 Behavioural components of fish movement that need to be considered in the design of fish passes.

Fish migration.

6.1 There is no experience of fish passes in Bangladesh and very little information on the swimming characteristics of the fish species of Southern Asia. Those characteristics and the likely response to various types of fish passes will have to be extrapolated from information gathered in other parts of the world. Before the design and operational characteristics of a fish pass can be decided upon, those aspects of the migratory response which are being catered for need to be identified.

6.2 Fish migration is most commonly associated with a behavioural response to currents. The nature of this response can, however, change during the life cycle of the species. The most fundamental distinction of response is between active upstream migrations, usually of adults to their spawning grounds and the passive combined active / passive downstream migrations of juveniles (Harden-Jones 1986; Pavlov 1989). For the population to be maintained in the river, both phases need to be possible (Fig.2).

6.3 Even in active upstream spawning migrations, active swimming phases do seem to alternate with shorter passive phases due to fatigue or re-orientation in complex current systems. At the time of spawning approaches the basic response of the fish to the current changes and the more sustained active upstream movement of the fish gives way to a more active / passive swimming behaviour. At this time the overall swimming performance of the fish declines and they are carried into side channels and onto the flood-plain. Once on the flood-plain there is little directional current as the flood advances rapidly but gently by the process of "creeping flow". Currents are generally below the threshold required to trigger the directional response and no doubt alter senses including tactile, olfactory and visual assist in the final orientation to the spawning and feeding grounds. Distribution is much more random and less aggregated and directional on the flood-plain. As the floods recede both adults and juvenile re-orientate to the current in their active/passive migration downstream back to the main channel.

6.4 Whilst this is the basic pattern, different species of fish differ in the extent of the various responses (Para 4.12-4.14). All except those categorized as "blackfish" have the adult active upstream and passive downstream migrations of the young (Fig. 2). The extent of the migrating routes for both places of category (i) can be very great. For example, Pangasius in recorded as travelling over 1,000km in Cambodia. Those of category (ii) may travel tens of kilometres whilst category (iii) is variable. For example Hilsa is found up the Padma as far as Rajshahi (Islam and Hossain 1983) a distance of some 250km from the sea.

Critical features of migratory behaviour; fish responses to current.

6.5 River discharges both provide the essential directional clues to physiologically prepared fishes to move upstream whilst also offering increased resistance to progress. Work in the erstwhile USSR has demonstrated that there are two ways in which fish species tend to follow their migratory pathways against the resistance of the current (Pavlov 1989).

6.6 Pelagic and some near-bottom dwelling species move near the surface of the water column. Illumination and not the time of day is the principal criterion for movement. Species which rely upon mainly tactile orientation, which includes many of the catfishes, for example, move against the current close to the bottom or in near-bank waters at night. The moon or other sources of light can inhibit migratory movement of these species.

6.7 Fish migrate normally at some intermediate cruising speed and only rarely at maximum speed. If current velocity in the main river channel exceeds their swimming ability, the fish will move closer to the bank where velocities are generally slower. The presence of turbulence or whirlpools tends to disorientate the fish. The swimming speeds of bottom fish tends to be rather slower than those of pelagic species, of the order of 0.5-1.0 times the body length sec^{-1} compared to 3-4 times the body length sec^{-1} of pelagic species. Nevertheless, the progress with respect to the bank is often similar since the bottom fish are moving in slower currents (Pavlov 1989).

6.8 Whilst most of the work on fish migratory responses have been carried out on European or North American species, the same divisions appear to be true for warm-water species. For example, tagged specimens of the pelagic characins Prochilodus and Salminus followed the gradients of flow velocity in the main river and moved during daylight hours whilst individuals of the catfishes Pseudoplatystoma and Luciopimelodus followed the contours of the bottom and avoided the zones where flow velocity was greatest (Poddubnyi et al 1981)[6].

6.9 Current velocity is the main initial stimulus to upstream migration and there are two indices which define the ability of the current to stimulate and the ability of the fish to respond. These are:

- **Threshold Current Velocity** (V_{thr}), the minimum current velocity which leads to an orientation reaction against the current (values range from 1-30cm sec^{-1})

- **Critical velocity** (V_{cr}), the minimum current velocity at which fish begin to be carried away by the water flow.

The V_{thr} needs to be exceeded to first stimulate the fish to begin upstream movement, assuming that physiological factors, such as the hormone cycle of ripening fish, are at the appropriate stage. It is therefore, vital that the stream of water coming through a fish pass must be higher than the V_{thr} in order to attract the fish upstream.

The V_{cr} should not be exceeded by the discharge of any regulatory device that the fish is expected to pass through against the current or the fish will be forced downstream.

6.10 The V_{th} and V_{cr} vary with size of fish and also according to the species or category of fish (Fig. 3). Typically, bottom-dwellers have critical velocities 2-3 times lower than those for species inhabiting the water column or surface layer. For these species there is a tendency for threshold velocities to be high and critical velocities to be low. The reverse is true for pelagic species. For example, migrating spawners of the bottom dwelling sturgeon have high threshold velocities of 18-25 cm sec^{-1} (Pavlov 1979) whilst the cyprinids *Abramis* and *Cyprinus carpio* have rather lower threshold velocities of 8-13 cm sec^{-1} . Smaller species have yet lower threshold velocities, of around 4-7 cm sec^{-1} (Pavlov 1989).

6.11 Fish are also attracted to points of higher velocity: attracting velocities are usually taken as 0.6-0.8 of the V_{cr}. For a wide range of European species and families, the V_{cr} range from 0.7- 0.9 m sec^{-1} (Malevanchik and Nikonorov 1984).

6.12 In Brazil, the flow of water though the Cachoeira de Emas fish ladder ranged between 0.5-2.5 m sec^{-1} (Godoy 1985). Below 0.5 m sec^{-1}, fish were not attracted to the pass, whilst above 2.3m sec^{-1} the tubulence at the foot of the ladder discouraged entrance into the system. In the Salto Grande fish lock in Uruguay, the flow could be controlled to provide flows of 0.1 to 1.8m sec^{-1} although optimium operation appeared to be around 0.9m sec^{-1} (Delfino, Baigun and Quiros 1986). The fish using the pass were a mixture of pelagic charachids and bottom-dwelling catfish but the range of current velocities appear similar to those reported from experience in the ex-USSR. There does seem to be a qualitative relationship between current velocity and numbers of fish attracted to the flow

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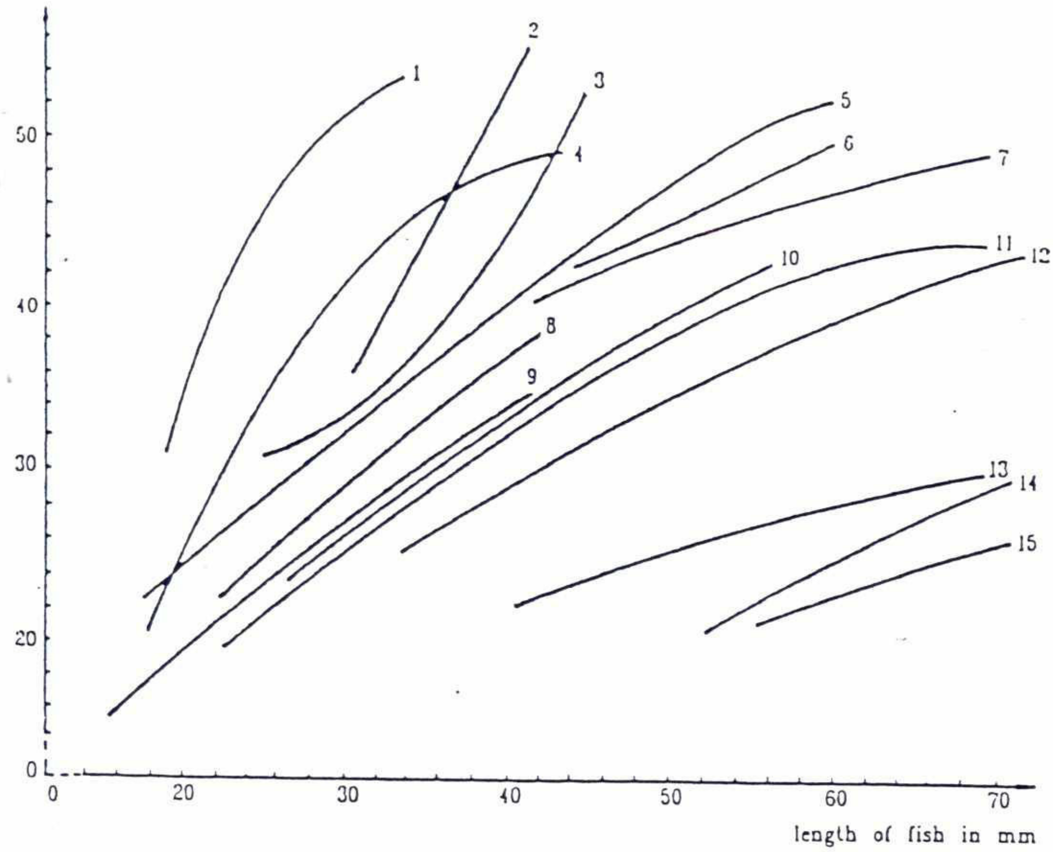
[6] Appendix I: Regional Appraisal of Migratory Patterns.

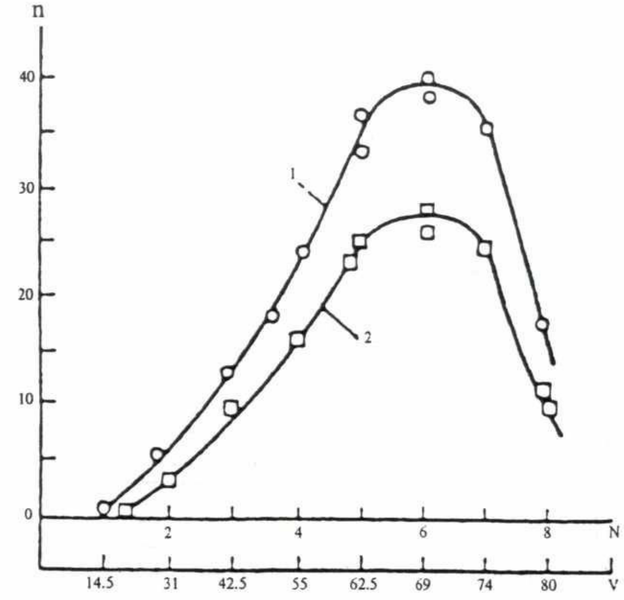


1. Alburnus alburnus. 2. Leucaspis delineatus. 3. Ruitilus rutilus caspius. 4. Carassius carassius. 5. Abramis ballerus. 6. Perca fluviatilis. 7. Vimba vimba. 8. Nemachilus barbatulus. 9. Cottus gobio. 10. Rhodues sericeus. 11. Tinca tinca. 12. Cobitis taenia. 13. Acipenser guldenstadti. 14. Husa huso. 15. Acipenser stellatus.

Figure 3 Critical current velocities for different species and sizes of fish:

(Fig 4). There is a progressive increase in the numbers of fishes moving upstream until a peak is reached. The peak for the two species mentioned in Fig. 4, around 70-80 cm sec^{-1}, is close to the V_{cr} range given above for the same species.

6.13 One final factor which is known to affect the performance and response of migratory fishes to cumec velocity is temperature. Maximum swimming speed is affected both by temperature and length of fish. It is possible to predict their effects (Beach 1984) using an empirical formula derived by Zoll (1982). The interaction of these two factors (Fig.5) shows that an 0.9m fish has predicted maximum swimming speed of only 4.3m sec^{-1} at 10°C but this increases to 9.6m sec^{-1} at 25°C. Since maximum swimming speed must be closely related to V_{cr} , the critical current velocity, then temperature must be expected to have an effect on this value. This may be however, a "within species" effect: there is no evidence that tropical species have a higher maximum swimming speed or critical velocity



Data for a floating fish-pass. n = number of fish/2 hour period, N = number of pumps operating, V = velocity of attracting flow in cm.sec. 1. *Abramis brama* 2. *Stizoestedion lucioperaca* (Pavlov 1979).

Figure 4 The relationship between quantity of fish entering a collection area and mean velocity of attractive flow.

than do temperate species. In fact, the range of current velocities found effective in tropical Brazil and temperate USSR appear to be similar.

7 Applications in Bangladesh

7.1 The concept of fish ladders to enable fish migrating against current to surmount permanent large variations in water level is generally not applicable in Bangladesh, as there are no main river structures intended to maintain water levels above the natural level. Under the FAP compartmentalisation programme and within existing empoldered areas the common regulatory structures are sluice gates; controlling both the inflow of water into an area and the outflow drainage from it. These are normally situated across secondary rivers and drainage systems that traverse embanked flood control schemes.

7.2 A regulator is basically a narrow gap that replaces the length of the flood-plain edge as the route for flow onto the flood-plain. Bypassing of the regulator is prevented by the embankments. The sill level and the width of the gap in relation to the area to be filled provide the regulation. Further regulation may be provided with gates.

7.3 Most often, the inflow of water is controlled by large undershot sluices (Fig 5), the gates of which can be opened between compartments and the rising river to allow controlled volumes of water into the cultivated area. The drainage sluices can be the same type (undershot) but can take the form of a large steel gate which opens automatically as the pressure builds up behind it. Simpler overshot gates (Fig 6) can be used for the same purpose. The drainage sluices allow the evacuation of rain water flooding from the

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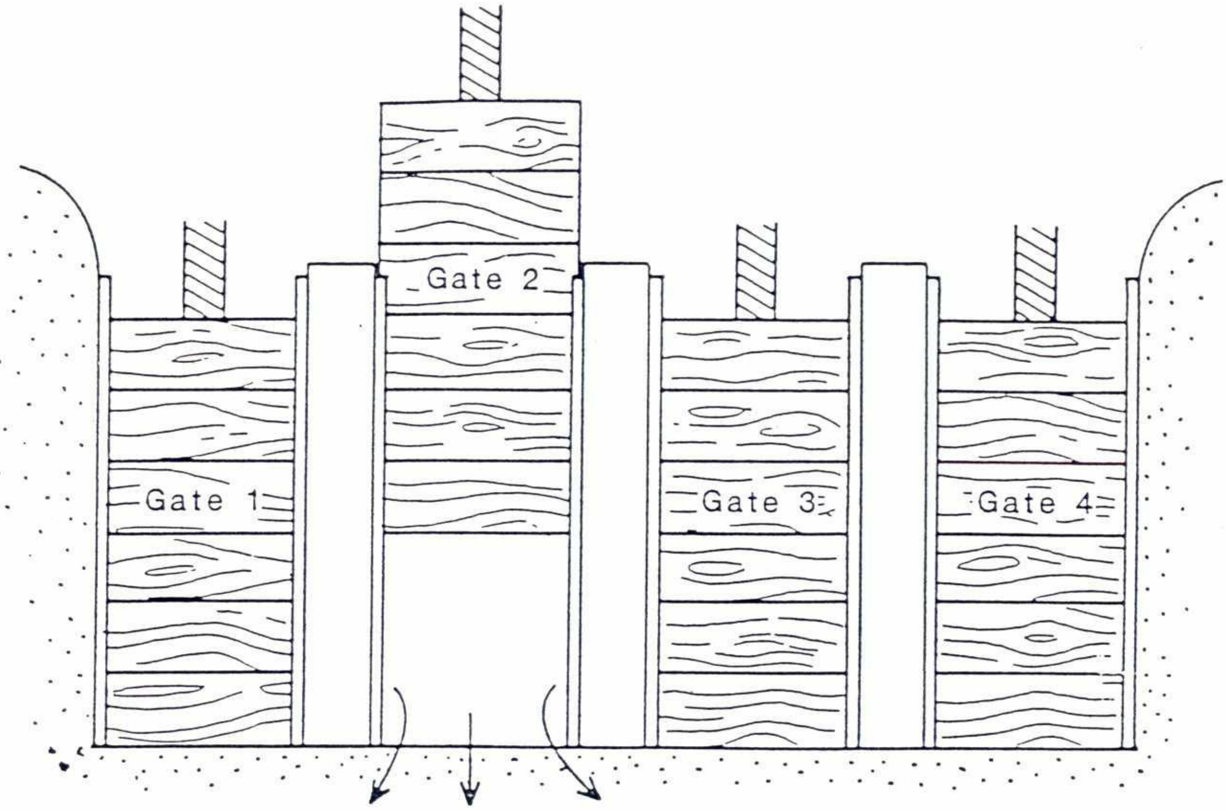

Figure 5 Undershot sluices with water flow controlled by four small gates. This enables a low discharge to be achieved using one gate only whilst still providing sufficient room for an ascending fish to pass under the gate. (After Beach 1984)

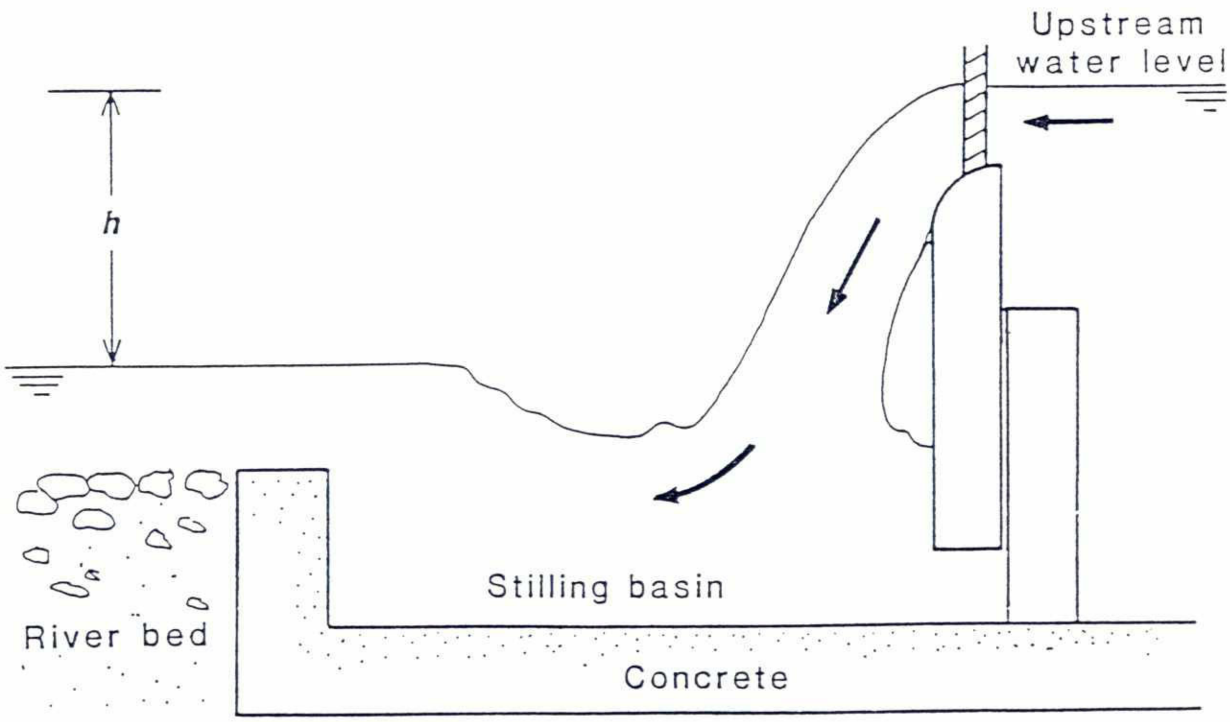

Figure 6 Overspill sluice with curved edge and stilling basin; this provides sufficient water depth for an easy approach and a smooth crest flow. (After Beach 1984)

compartment during the rains and allow the water level in the compartment to be finely controlled in relation to the inflow channels to facilitate rice cultivation.

7.4 The requirement in Bangladesh will not often be for the design of additions to regulatory structures for the benefit of fish but for an assessment of the structural design of the regulator as a whole in respect of its "fish friendliness". This is inseparable from and secondary to the planned regulating function of each particular structure. The starting point is therefore a detailed specification of the function of the regulator. For example, a regulator is planned to hold water level well below natural level for the benefit of farmers and it is not necessary to open the gates for long to maintain the required level. On the other hand fishing interest may require that the gates are at least partly open for a long period. Difficulties with energy dissipation due to lack of water depth downstream and the high head across the structure may rule this out. It is possible on the evidence available to give some initial guidelines to features of a "fish friendly" structure and this has been addressed in the following but standard designs cannot be set.

Modes of gate operation

7.5 The only type of gate considered here is the vertical lift gate which has the advantages of economy, suitability for a wide range of heads and suitability for two way flow. Flow over or through other types of gate is not very different in hydraulic terms to the vertical lift gate in open or other its modes of operation.

7.6 The gate can be operated in three modes, undershot, overshot and retracted as shown in Figure 7. Overshot and retracted modes have similarities but the flow characteristics of the latter are sufficiently different for it to be considered as a separate mode.

7.7 On the assumption that there is a fixed flow area regardless of the upstream head (eg through a pipe of fixed diameter or an undershot gate on a regulator) then under free flow conditions the discharge rises in proportion to the root of the upstream head. In other words discharge rises slower than the upstream head. Under free flow conditions, if the discharge area is increasing as well as the head (eg under natural conditions) then the the discharge rises in proportion to the upstream head raised to the power 1.5. The discharge therefore rises at a rate faster than the upstream head.

7.8 An undershot gate has a fixed flow area regardless of the upstream head and therefore discharge rises at a slower rate than the upstream head, whereas with an overshot or retracted gate discharge rises at a faster rate than the upstream head. Head is measured above the crest of the gate and the "crest" of the retracted gate is the regulator sill.

7.9 Discharge of the overshot and undershot gate can be varied at a given upstream head by changing the level of the top or bottom of the gate respectively. Discharge for a retracted gate is fixed relative to the upstream head and overall discharge can only be changed independently be varying the width of the opening. In practise this means varying the number of openings and is then only applicable to multi-gate structures.

7.10 These varying flow characteristics have implications for downstream level control, downstream energy dissipation and fish passage that are explored in more detail in

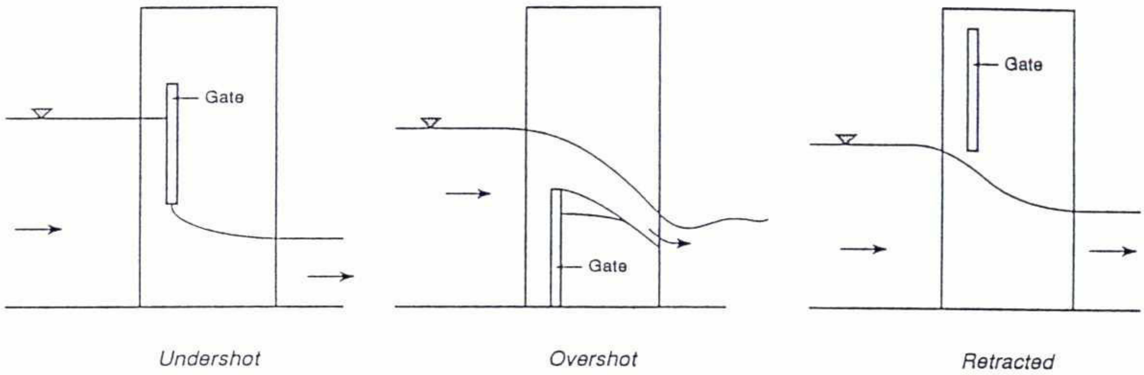

Figure 7 Modes of gate operation.

following sections.

8 Interaction of regulator and fish

8.1 The fish spawning cycle begins at the first freshets of the pre - South West monsoon when the adult fish move up river to the spawning grounds. Soon after the first eggs, larvae, hatchlings and fry will begin to drift downstream with river current since they have little or no motive power. River levels will still be quite low. Evidence so far suggests that the abundance of migrating hatchlings will be highest in the early stages of the cycle followed by a decline over a period of two months but may continue at a lower intensity for a further period of time particularly if monsoon rainfall is late or low. Typically, this period will extend from May to August.

8.2 Although the gates should be open as the river rises, inflows probably have little effect on attracting migratory adult and juvenile fish into the compartment as the current is flowing in the wrong direction to attract the fish. Indeed, in certain polders such as BSKB beel, where there is a tidal effect which can cause stong inward flowing currents into the canals of the beel, young stocked silver carp have been seen migrating **out** of the beel against the current.

8.3 However, the inflow though the sluices may draw fish in with the current; allowing eggs and hatchlings to enter the compartments. The extent of passive larval drift into the compartments is not known and is currently being studied by FAP-17 and FAP-20. Nevertheless, it is clear from the recent Third Fisheries Project Monitoring Programme that wild major carp (type (ii) migratory spawners; Para. 3.14.) are not abundant in enclosed beels. Also uncertain is the timing of peak fry and juvenile drift in comparison with maximum inflow allowed through the drift.

8.4 It is the drainage sluices which are most likely to attract actively migrating fishes. Drainage would commence as the rains build up and discharge the excess of water into the main channel at a time when the fish are moving upstream. If that discharge has the correct current velocity, probably in the range of 0.7-1.0 m sec^{-1}, and if the configuration and timing is also correct, then it is possible that migrating fishes may pass into the compartments through the drainage sluices[7]. If these conditions were not met then the sluices would act as a barrier, which would certainly be the case if pumped drainage is used.

8.5 By reference to the reports on fisheries already issued by other Flood Action Plans and from discussions with various interested parties, the consensus is that regulators affect fish and fisheries in two distinct ways:

- by changing the time and pattern of flow onto the flood-plain; and

- by causing actual impediment or harm to the fish.

Timing and pattern of flow through a regulator

8.6 The pattern of flow onto the flood-plain may be changed merely by the presence of the regulator, by the gate mode used and by the gate operation programme. Possible effects on fish passage and distribution are examined below.

8.7 Of considerable relevance to the effect of regulators on the passage and distribution of fish fry is the timing of the period when fish fry are on the move. It is generally accepted that the peak density of fry occurs early in the monsoon cycle and declines thereafter at an indeterminate rate. The period begins very soon after the start of the monsoon season and on present evidence will normally cover a period of more than two months. However, recent data collected by FAP-17 and FAP-20 from the 1992 season indicates that a longer spawning period may, however, be linked to late or low monsoon floods (Fig 8). Analysis of the results is not yet sufficiently advanced to draw firm conclusions; FAP-17 and FAP-20 are awaiting the results of the 1993 season.

8.8 At the low pre-monsoon water levels when spawning migrations take place, the gates of drainage regulators should be fully open and the sill level should have been placed low enough to permit natural passage for fish. In some years there may be late spawning

[7] On the assumption that there is frictionless free flow downstream then the water velocity is equal is a function of gravity (acceleration 9.81 m sec^{-2}) and water head difference (h): $V = 2(gh)^{0.5}$. Assuming a model length of an adult migratory species to be 25cm then the critical velocity V_{cr} could range between 1.5-2.5 m sec^{-1}; equivalent to crossing a stream head of 10-30 cm. However, this does not take into account velocity loss due to frictional drag. Fish exploiting the velocity differences due to turbulence could no doubt ascend greater head heights than this theoretical calculation indicates.

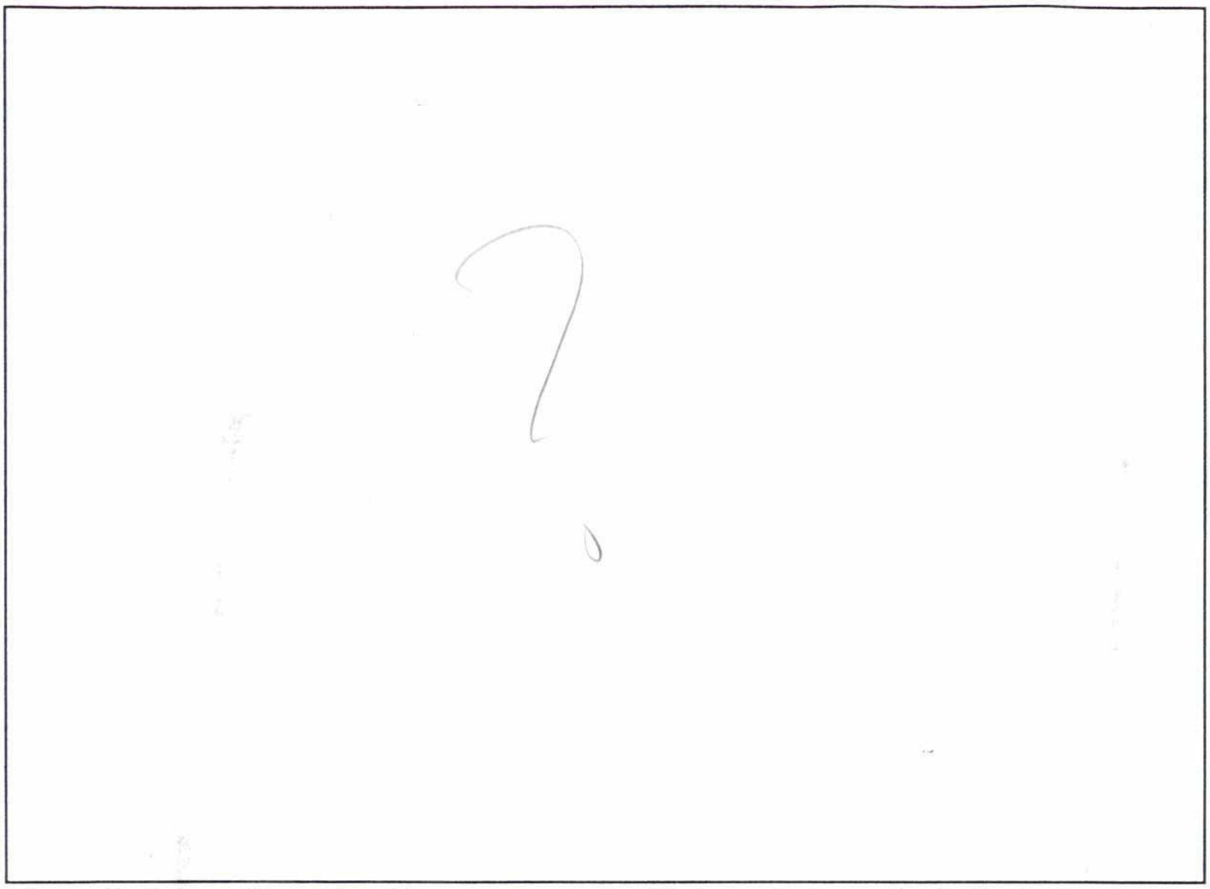

Figure 8. Seasonality of hatchling occurence in Dhaleswari river, North Central region.

runs. This would generally be when rainfall is poor and the rivers are still slow enough for fish to swim upstream later in the monsoon season. Under these circumstance, regulators should not be generating heads and velocities high enough to stop the fish. Consequently, ladders for fish migrating to the spawning grounds are not a common requirement at regulators.

8.9 Regulators that control the inflow of water on to the flood-plain should have sills set at a low enough level to allow flow into the flood-plain at the earliest stage of the flood cycle. When flow first enters, the driving head will be small and the discharge into the flood-plain, relative to that entering the unrestricted flood-plain, will be little more than the proportion of the regulator width to the open flood-plain length. This low flow will cause the level in the flood-plain to lag behind that in the river and the increased head across the regulator will increase the rate of flow. The width of the regulator will determine the maximum difference in head. The regulated volume in the flood-plain therefore lags behind that entering the natural flood-plain with respect to time.

8.10 This is illustrated diagrammatically in Figure 9. For simplicity, volume in the natural flood-plain is shown as increasing linearly with time. The lag increases as the regulator width reduces. If line A represents an allowable volume, and therefore level, in the flood-plain then the regulated flood-plain will reach it at a later time than the natural flood-plain would, provided the river level continues to rise above or holds a peak for some time at the level represented by A. Otherwise the regulator will cause a shortfall in the volume of

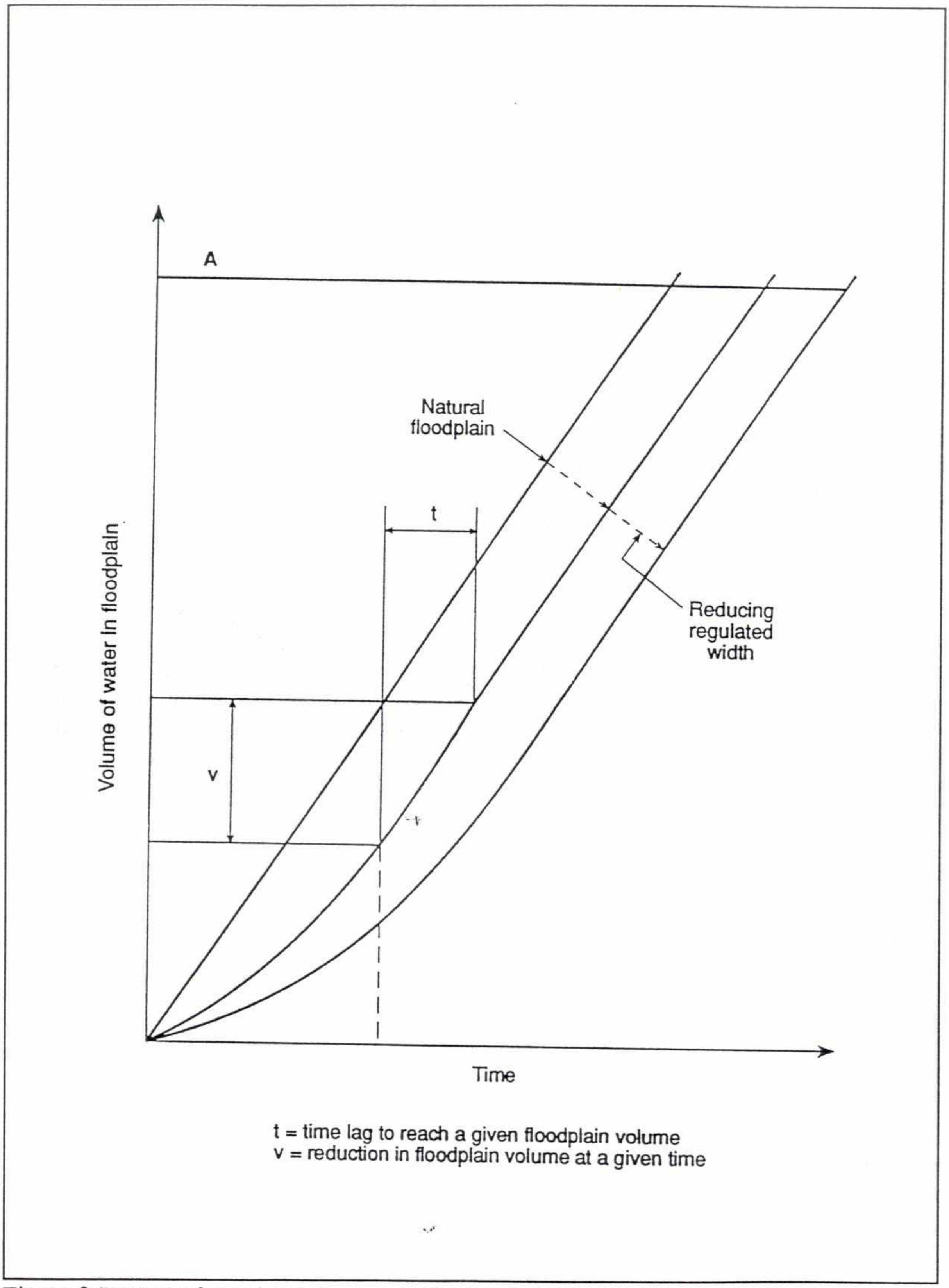

Figure 9 Pattern of regulated flow onto the flood-plain.

water on the flood-plain.

8.11 Assuming that there is no shortfall in the volume of water on the flood-plain, the total fish passing through and dispersing relative to the natural flood-plain will depend on whether the time lag inherent in the use of a regulator has an effect. If the slow build up in volume in the flood-plain in the early stage of the cycle coincides with the greatest abundance of fish fry then the regulated flood-plain will not be accessible to fry with quite as high an efficiency as the natural flood-plain.

8.12 In practise, the situation is more complex than outlined above, depending as it does on the contouring of the flood-plain and the length of the flow paths through the flood-plain. Investigation with an advanced numerical model is therefore necessary to evaluate the full effect.

8.13 Although the effect may be small, the change in the pattern of flow onto the flood-plain due to regulation will tend to have a negative influence on flood-plain fisheries even when regulated only to exclude exceptional floods and not otherwise change the balance of advantage between agriculture and fisheries.

The influence of gate type on inflow pattern

8.14 The fully retracted gate gives the maximum discharge for a given upstream water level (Para. 6.7) and the regulator should therefore be operating in this mode at the start of the flood cycle. If undershot gates are being used, discharge in relation to upstream water level slows down from the moment when the opening is submerged on the upstream side. For a regulator of a given width therefore, undershot control will generate a larger head difference between river and flood-plain than overshot and therefore a greater time lag in terms of entering water volume.

8.15 To maximise the volume of water in the flood-plain while fish hatchlings are at their most abundant, retracted gate operation should continue up to the point where the downstream level is at a height were gate regulation is required. Undershot gates should therefore have a top level at least this high.

The influence of gate operation on inflow pattern

8.16 The prime requirement with regard to fish passage efficiency is that there is a flow through the regulator throughout the period when fish fry are on the move in quantity. As described in Para: 7.8, this period is not yet closely defined but is not likely to be less then two months. Positive consideration should therefore be given to maintaining flow over this period and particularly early in the period even though it may be possible and at times more convenient from a water level control point of view to have the regulator closed during this period.

Sources of impediment and harm to fish

8.17 Under this heading, present evidence identifies four effects detrimental to fish capture efficiency.

i Structures that are impassable to fish
ii Damage to fish by rapid changes in pressure
iii Physical damage to fish by contact with the structure
iv Damage to fish by turbulence.

Impassable structures

8.18 The undershot gate is the feature usually in mind when impassable structures are discussed. The approach flow to an undershot gate is shown diagrammatically in Figure 10a. It can be seen that the gate draws flow from the full approach depth but a pocket or pool forms against the gate. The size of the pocket varies, tending to extend further from the gate as the ratio of gate opening to upstream depth increases. The pocket is not still water; the drag of the high velocity stream underneath rotates the flow comparatively slowly in a reverse direction. There is a constant interchange of water between the main stream and the pocket and material of any type in the pocket will tend to be held for a period but eventually ejected.

8.19 Input to the pocket is mostly from the surface layer of the approach flow and floating bodies are certain to enter it. However, only material with a very high flotation would resist the drawdown forces. Developing fish eggs are, in many cases, of neutral buoyancy and it is extremely unlikely that an undershot gate would do more than briefly delay a small number of hatchlings or fry in passage. It is not clear in the case of very young fish whether a delay is damaging or, if so, what degree of delay is significant. They could, however, be subject to very high accelerations on exit from the pocket.

8.20 An overshot gate operating with a low tailwater level can develop a flow pattern on the downstream side with a slow moving pocket of water behind the nappe as shown in Figure 10b. If it occurs, the effect on the passage of fish is likely to be insignificant.

Change in pressure

8.21 Fish adjust to changes in pressure with the aid of the swim bladder. The concern with structures is that they will impose changes in pressure on passing fish at such a rate that the fish is unable to adjust quickly enough to avoid damage to the swim bladder. It is reasonable to assume that very young fish will be at greatest risk.

8.22 The specific energy of the flow is the depth of flow (pressure) plus the kinetic energy (velocity). Therefore changes in velocity are echoed by changes in pressure. For a given discharge and upstream depth, the undershot gate will show the greatest variation. The overshot gate will also subject passing fish to changes in pressure but rather less than the undershot gate in range and speed of change. Flow through a retracted gate will generally give the least and slowest changes of pressure.

Contact with the structure

8.23 Damage by physical contact with a gated regulator, operating with any gate mode, is likely to be limited since there is relatively little structure in the flow and the streamlines will tend to guide fish round such parts as pier noses.

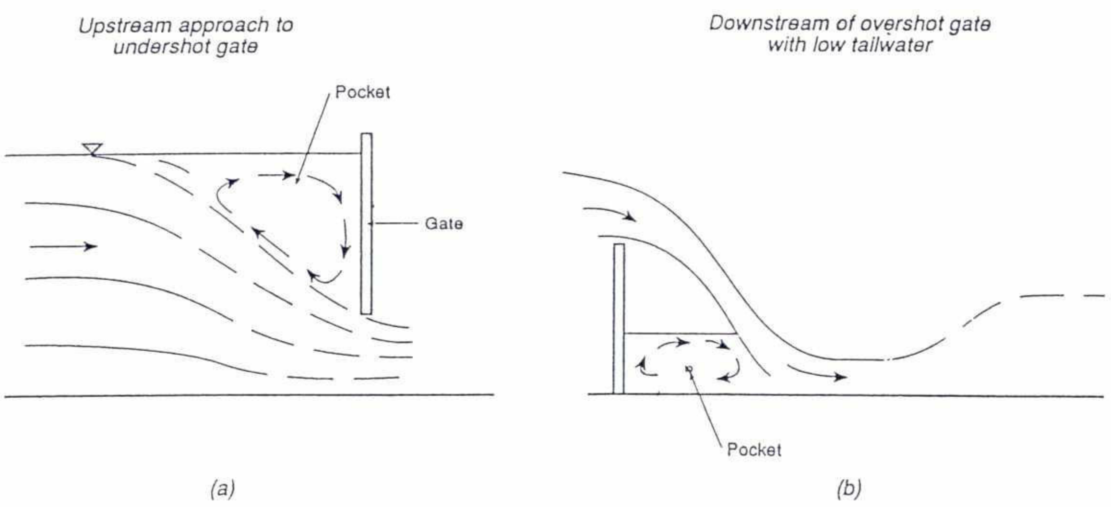

Figure 10. Occurence of slow flow pockets.

8.24 A culvert or channel may, however, force the fish into close proximity to an extensive surface while travelling at high velocity. The danger of damage to fins and scales is therefore increased. A sharp edged entry creates turbulence just inside the entry which is not a problem hydraulically but will make matters worse for fish passage. Such designs are quite common and an example is shown in Figure 11. Where fish passage is expected, a streamlined entry, including a streamlined soffit, would improve the situation to some extent.

8.25 Under some circumstances, energy is dissipated by impact of the flow against a solid boundary and this is clearly a hostile environment for fish. This situation can occur downstream of overshot gates when the ration of tailwater depth to head over the weir is too low as shown in Figure 10b.

8.26 Impact can also be a deliberate means of dissipating energy. Figure 12 shows an example of an impact energy dissipator where the outflow from a culvert is directed against a vertical wall and then exits underneath the wall. In hydraulic terms this is a compact, highly efficient energy dissipator and is particularly applicable to outlets where there is little or no tailwater to absorb the flow energy. Without the dissipator, erosion damage downstream could be severe. In every respect, this type of dissipator is damaging to fish but equally, it would be damaging to discharge fish into an area containing little or no water in any case. It is probable that in situations where this type of outlet is used, passage

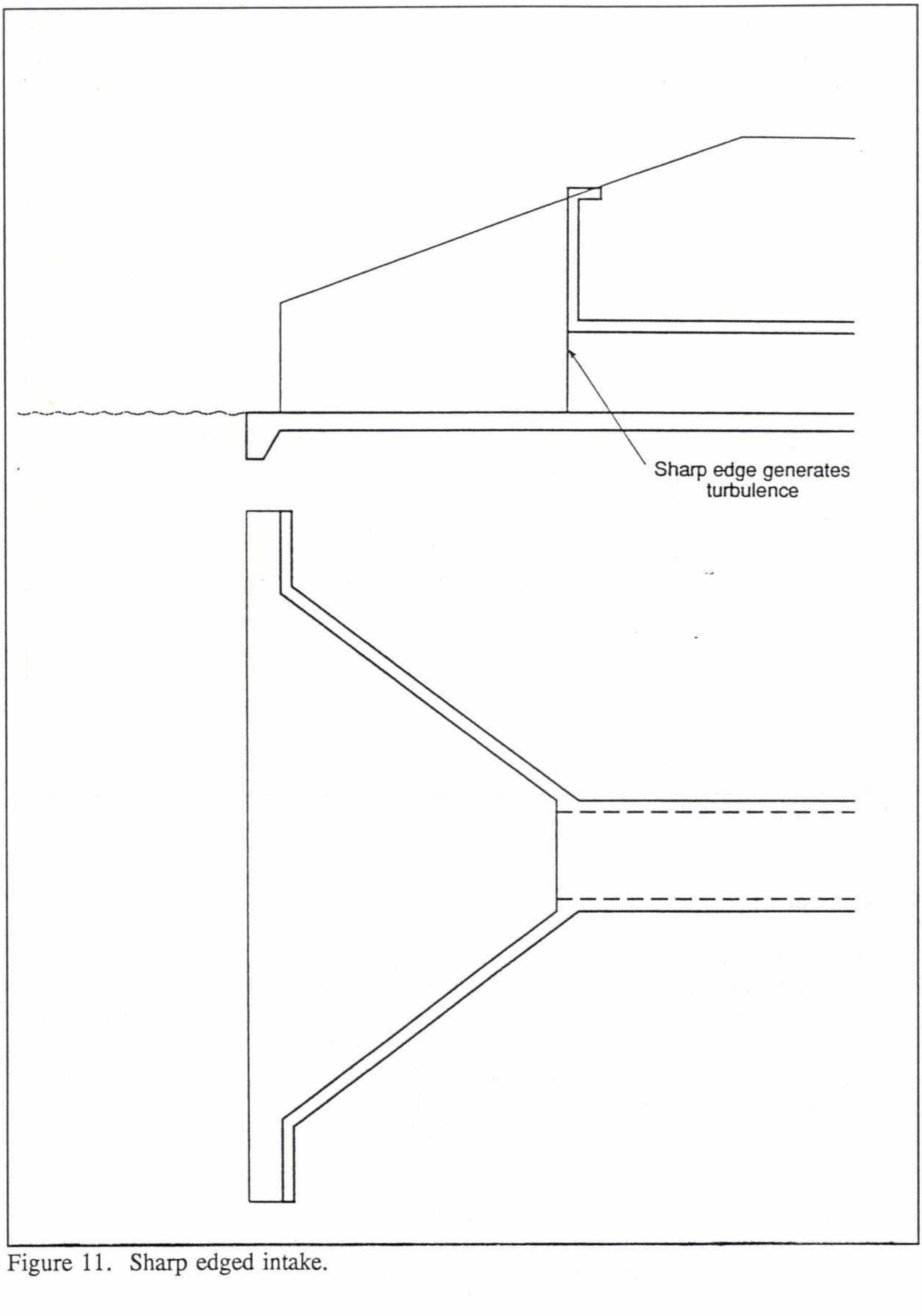

Figure 11. Sharp edged intake.

of fish is not a major concern. If it is, it may be possible to double the outlet with one more friendly to fish that is brought into operation when there is sufficient downstream water depth to accept the fish and dissipate the energy.

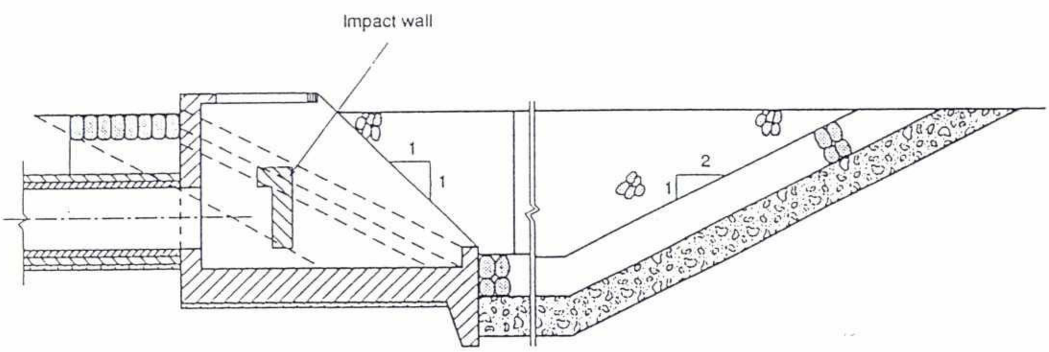

Figure 12 Impact dissipator.

Turbulence at structures

8.27 Turbulence downstream of regulators has positive and negative aspects that require a compromise. A regulator is a deliberate restriction of the natural flow area and there will always be a head difference across the regulator at some time in the flood cycle and usually most of the time. This head difference represents an energy that must be dissipated. Apart from systems used on high dams to dissipate energy with jets in the air, energy generally has to be dissipated by turbulence that eventually turns it to head. Turbulence is therefore necessary and must be well controlled to avoid erosion damage downstream of the structure.

8.28 Fish in turbulent flow can be subjected to rapid fluctuations in pressure, high G-forces, disorienting eddies and impacts (of fast flow on slow flow). No quantitative evidence of these effects is available but it is clear that if turbulence is necessary it should be minimised where possible in the interests of fish.

8.29 Any discussion of turbulent energy dissipation downstream of structures will include refences to critical flow, supercritical flow, subcritical flow and hydraulic jump. These terms are briefly explained in Appendix III.

8.30 The flow conditions most commonly found downstream of a undershot gate are shown in Figure 13. In Figure 13a, the issuing jet is supercritical and the return to subcritical flow that will continue down the river occurs in the hydraulic jump where turbulence will be considerable as energy is dissipated. The jump will be at its most intense when the gate opening is small and the features of turbulence set out above as most damaging to fish will be most evident. In general, the wider the gate opening as a proportion of the upstream depth, the less intense will be the turbulence.

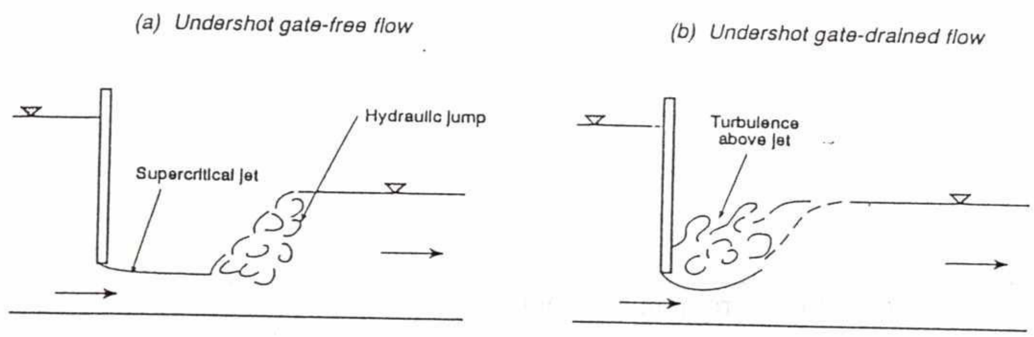

Figure 13 Flow downstream of undershot gate.

8.31 The hydraulic jump only forms at or close to a particular downstream depth. If the depth is too low, the high speed jet will continue over a long distance until it is gradually slowed by friction. In terms of fish passage, this might well be an improvement but in hydraulic terms it would pose an unacceptable threat of damage to the river channel downstream and to the security of the structure.

8.32 If the tailwater depth is too high for a stable hydraulic jumps, the tailwater will run over the jet as in Figure 13b. There will then be surging turbulent water above the gate opening as it is dragged away by the jet and falls back but most fish would be unlikely to pass through this area and the underlying flow would be relatively smooth.

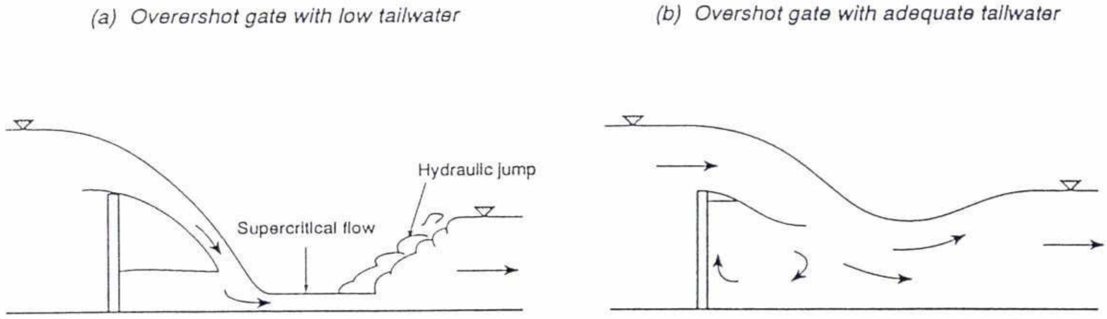

Figure 14 Flow downstream from an overshot gate.

8.33 Possible flow conditions downstream of an overshot gate are shown in Figure 14. Figure 14a shows the situation where the tailwater is low. The jet pushed the water away and, as with the undershot gate, forms a hydraulic jump further downstream or in extreme circumstances continues as a high speed jet. If the tailwater is high enough, the downstream conditions will appear as in Figure 14b with, in most cases, a comparatively smooth dissipation of energy.

8.34 Flow through a fully retracted gate over a broad sill is the smoothest form of the overshot gate and therefore the generally the most fish friendly mode in term of turbulence.

8.35 It is not possible to say that one mode of gate operation is best because the turbulence downstream of a regulator is determined principally by the head difference across the regulator (the energy head) and the depth of tailwater available downstream to absorb it. The latter is determined by the regulation programme. The choice of gate operation may therefore be limited by these two factors.

9 Information from site visit to Chargat regulator.

9.1 A site visit was made to the regulator on the River Barral at Charghat. The regulator controls inflow to the Barral from the Padma, runs roughly parallel to the Padma and outfalls into the Jamuna. At the time of the visit (24 August '92), monsoon rainfall had been unusually low and conditions may not have been typical. The regulator has three undershot gates separated by piers and estimated to be 12ft wide. Each gate was opened to approximately 8 ft. Gauge boards upstream and downstream of the regulator showed the head difference to be 0.4m. At this head and depth of water, the gates were drowned and flow was as shown in Figure 13b and described in Paragraph 7.28 - 7.35. Water between the piers above the gate outlets was heaving with frequent surges creating surface waves. Although the effect was noisy, the flow a short distance downstream was comparatively smooth.

9.2 Hilsa were being caught downstream of the regulator with scoop nets on poles around 24ft long. The nets were being rope hauled in the downstream direction implying that the fish were moving upstream. If this were so, the fish would tend to rest before attempting a run through the regulator and congregate in numbers. There was no fishing taking place upstream suggesting that the fish were not aggregating upstream or that very few were getting through.

9.3 The fish being caught were mostly about 0.22m long with an occasional one up to 0.5m long. The mean velocity through the regulator was estimated to be 2.8 m sec^{-1}. Detailed information on burst speeds for specific fish species is not at present available. However, for an "average" fish (Zhou 1982) with a length of 0.22m, a burst speed above this would be possible if the water temperature was above 20 degrees C but the burst endurance would be very short.

9.4 With all gates open, the fish would not be able to start a run from close to the gates. It would therefore be difficult for the small fish to pass the regulator although the larger ones would be unlikely to have much difficulty. The significance of the movement of Hilsa of this size up this river at this time of the year is not known, neither is the operating programme for the regulator. However, it emphasises the point that when regulators are known to be in the path of migrating adult fish care should be taken to ensure that the regulator does not develop a high head at the time the fish are passing. This is a danger when water levels are low and regulation requirements alone allow a regulator much narrower than the natural channel.

9.5 Of particular interest at the Charghat Regulator is that it was noted on an early reconnaissance by the FAP-17 field team that savar (hatchling) nets were in use both upstream and downstream of the regulator suggesting that fish fry were negotiating the regulator in sufficient numbers to make netting them downstream worthwhile. At the time of the visit to the site in late August, only one upstream net was in use. FAP-17 will continue to monitor this site in the expectation that it will provide valuable information on the interaction of regulators and fish fry.

10 Louhajang Regulator Designs

10.1 With the co-operation of Flood Action Plan 20, a number of runs were made with the Mike 11 numerical model which showed the effect of gate operation on regulation for the proposed regulator on the Louhajang River[9].

10.2 Since fully retracted gates appeared on initial assessment to offer the most benefits to fish passage, the first runs were made using regulation based only on changing the number of fully open vents. Problems were noted in the regulation:

i The open area could be changed only in relatively coarse steps so that fine regulation was difficult.

ii When a change was made, the characteristic that discharge rises at a faster rate then upstream water level and vice versa caused fairly rapid change in the controlled level that would have called for frequent gate changes to maintain a reasonably steady level.

iii Combination of the two features above could cause a hunting effect that would make smooth regulation particularly difficult.

10.3 An overshot gate has the same characteristics as a retracted gate and some of the same difficulties could arise. A regulator that relies entirely on overshot gate control does not therefore appear to be a feasible proposition. On the other hand, the undershot gate characteristic of a discharge that rises and falls more slowly than the upstream level looks more suited to fine, stable regulation.

10.4 Additional runs were made on the FAP-20 numerical model with regulation by undershot gate and it was found that regulation could be smoothly achieved.

10.5 The initial conclusion is therefore that the requirements of regulation and the requirements of fish passage are not mutually compatible and some compromise will have to be devised for a practical regulator.

11 Situation review

11.1 Assessment of the main points of a "fish friendly" structure are summarised below, along with the practical limitations:

General

11.2 Where the downstream drift of fry continues for two to four months, the regulator should allow some flow throughout this period to maximise fish passage. If the regulated level inside the flood control scheme is kept low, the head across the regulator could be very high during the period and might create control difficulties with a part of the regulator open.

11.3 When the time of peak fry abundance arrives, the discharge through the regulator should be equivalent to that onto the natural flood-plain i.e. the downstream level should be rising as fast as the upstream level. If this requirement cannot be met, a wider regulator

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9 Appendix IV Structures for the compartmentalisation of the Tangail area (Flood Action Plan 20).

is required. However, a wider regulator would require gate control to be initiated earlier in the flood period to restrict the rise in downstream level. At the opposite extreme a very narrow regulator would be able to restrict the rise in downstream level within acceptable limits without any gate control at all and would be most advantageous to fish passage. Flexibility of operation is, however, restricted with a narrow opening should a future change in the controlled level be required. On balance, therefore, a wide regulator would be preferable as it improves conditions early in the monsoon cycle when most fish fry are on the move.

11.4 No type of gate operation is considered to be totally impassable to fish. If stoppage or delay did occur it would be at undershot gates. From the point of view of limitation of rapid changes in pressure, contact with the structure and turbulence, overshot or retracted gates are preferable to undershot gates.

11.5 Retracted gate operation may lead to problems of energy dissipation due to unsymmetrical flow downstream. From the point of view of smooth water level regulation, undershot gates have definite advantages over overshot or retracted gates.

12 Discussion and recommendations.

12.1 Retracted gates provide the maximum flow rate and the least hindrance to passage of fish and fry and should be used for as long as possible from the start of the monsoon. Maximum opening level of undershot gates should allow for this.

12.2 The undershot gate gives the most easily manageable control of downstream level and, since regulation is the primary purpose of the structure, this should be the principal form of control when gate control is brought into operation.

12.3 Outer vents should be arranged for overshot or retracted operation throughout to facilitate fish passage and should be sized so that in normal circumstances they can be left in use continuously for the first four months of the monsoon without seriously interfering with the control function.

12.4 Operation may take a number of variations as shown in Figure 15. Figure 15a shows an outer vent running with a retracted gate. Run in this way, the discharge per unit width could reach high values. To maintain this mode of operation to high head differences across the structure, the vent/vents might then have to be very narrow to avoid undue interference with regulation. Narrow vents would increase the risk of harm to fish by contact with the structure.

12.5 A preferable option to avoid using very narrow outer vents is shown in Figure 15b. A gate of fixed height is lowered to give overshot mode as the first step in finer control. As an example a gate whose height is 50 percent of the upstream depth will reduce the vent discharge by 65 percent. For further control a second gate can be partly or fully closed. Partly closed (Figure 15c), the gate will be undershot but downstream turbulence is unlikely to be as intense as with an opening at sill level. As refinement of Figure 15c a double gate may be used as shown in Figure 16a. This would allow further control to be always overshot.

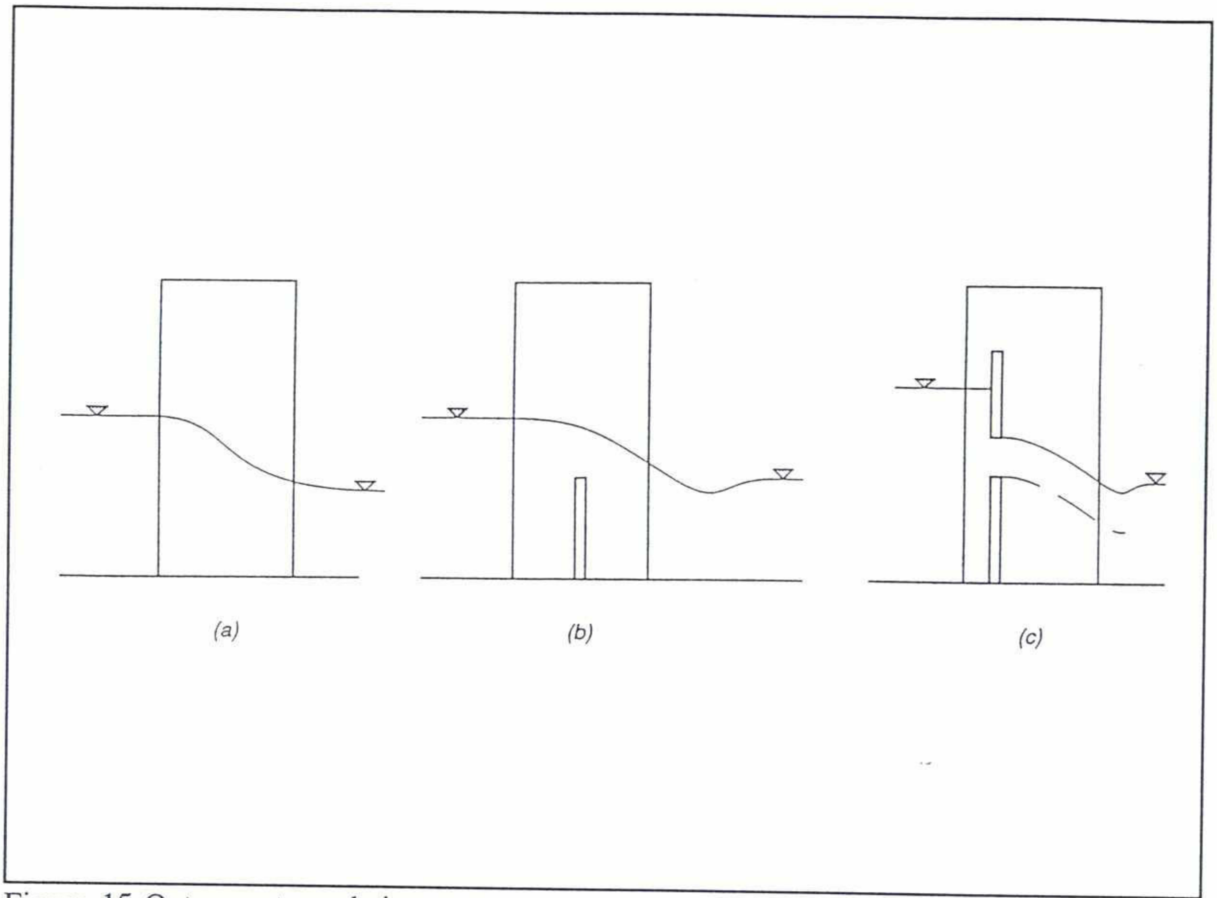

Figure 15 Outer vent regulation steps.

12.6 A variation on the layouts shown above is to install a separate vent at the side (preferably both) with a higher sill level than the main vents which would in effect be fixed at the position reached in Figure 16b. A lifting gate recessed into the sill would provide further control similar to Figure 16a. The sill would be at such a level that flow through the main vents would not be gate controlled before the sill was overtopped. Downstream of the fixed sill, a ramp could be fitted as shown in Figure 16b. If there was already a large head difference across the structure by the time the sill was overtopped, the downstream slope could be and advantage in reducing turbulence. This would, however, imply that downstream level was being retarded by use of the gates or of a very narrow regulator to the overall disadvantage of fish access. Assuming that a large head difference was not being allowed to develop this early in the flood, energy dissipation downstream of a gate (Figure 14b) would be no more damaging to fish than with a slope incorporated.

12.7 Flow downstream of the overshot side vents would in general be less turbulent than that from the undershot main vents. The side vent piers should therefore be extended to separate the two streams until uniform subcritical flow has been re-established downstream (Figure 17).

13 Conclusions

13.1 A regulator cannot completely reproduce the pattern of flow on an unregulated flood-

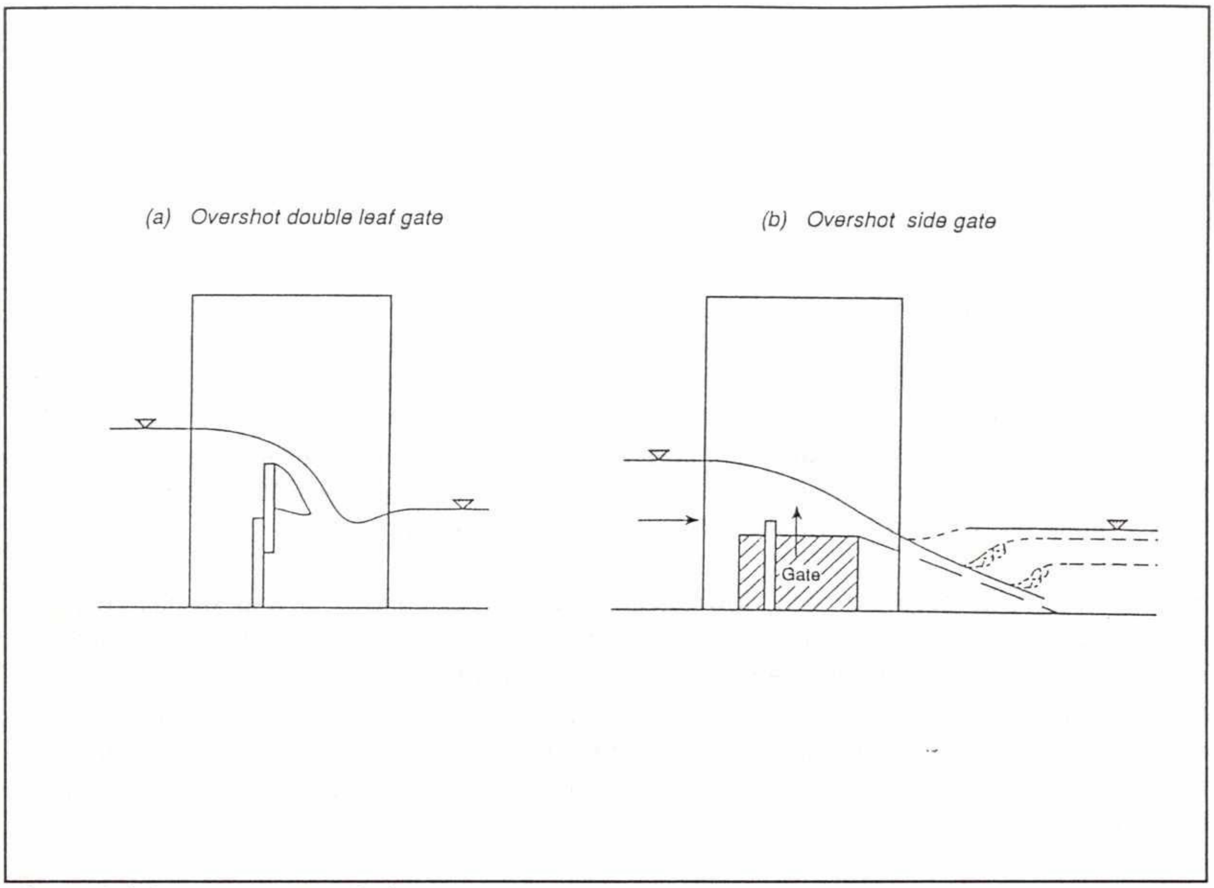

Figure 16 Outer vent regulation.

plain. Even when a regulator is intended only to exclude catastrophic floods and not otherwise change the natural sequence of flooding, there will tend to be negative effects on flood-plain capture fisheries.

13.2 The negative tendency stems from a time shift in the pattern of movement of fish hatchlings relative to the rate at which the flood-plain fills as a result of the restricted entry area to the flood-plain. This conclusion is based on the assumption that fish fry abundance reaches a distinct peak very early in the monsoon cycle but quantitative data is sparse. Given that this assumption is true, a regulator wide enough to minimise flow restriction through this early period (ie low head loss across the structure) is desirable.

13.3 Data related to the spatial and temporal distribution of migrating hatchlings is currently being collected by FAP-17 and FAP-20.

13.4 Free surface flow through regulator gates, otherwise known as overshot flow, is preferable to undershot flow to facilitate fish passage through a regulating structure. In this context, a narrow regulator that requires little or no gate operation to control the downstream level appears advantageous but conflicts with conclusion of para. 12.2. In terms of overall "fish friendliness", however, conclusion para. 12.2 takes precedence; a narrow structure lacks operational flexibility and increases energy dissipation problems downstream.

13.5 The distinctive operational feature of a flood-plain regulator is that it is the downstream level that is controlled. In these circumstances, the flow characteristics of an undershot gate are preferable to those of overshot gates for smooth water level control. The conclusion is, therefore, that a practical compromise between efficient regulation and "fish-friendliness" will require a combination of undershot and overshot gate operation.

13.6 Overshot gates are preferable to undershot gates for fish passage due to flow characteristics at the gate and downstream of the gate. The further contention that they are also preferable due to the habit of fish fry of passively migrating only in the surface layers of the flow is not fully supported by current evidence. Evidence is available from FAP-17 and FAP 20 field studies that hatchlings are evenly distributed throughout the water column. Further data collection and analysis is being carried out by FAP-17 and FAP-20 to determine the vertical distribution in terms of numbers and species.

13.7 A particular problem with downstream water level control is that discharge and downstream water level are not closely related. The relationship between the amount of energy to be dissipated and the depth and volume of downstream water available to absorb it can therefore vary over a wide range. The design of downstream energy dissipation measures is then difficult not only in relation to fish passage but also in relation to channel erosion. It is therefore essential that energy dissipation at flood-plain regulators is analysed over the full range of flow combination that could occur.

13.8 Particular attention should be paid to regulator designed to control downstream water level at well below natural water level for the benefit of agriculture. Unexpectedly extensive bed and bank protection may be necessary to avoid dangerous scour. Conditions for fish passage may not be worse and could actually be better due to a more gradual dissipation of energy. The threat to the security of the structure will be the primary concern.

13.9 The danger of rapid changes of pressure and of turbulence to fish survival can be based on common sense reasoning and anecdotal evidence. More quantitative evidence is required on these points to establish whether more extensive and/or expensive modifications to regulator designs could be justified.

13.10 The high rise fish passes needed to allow fish migrating against the current to pass permanent barrages may not be a pressing requirement but there are occasions where structures could impede migration of adult fish. The methodology for designing this type of fish pass is available but further investigation of the swimming performance of the major fish species involved is required to allow it to be applied[10].

13.11 Regulators have the potential to cause catastrophic damage downstream. In view of the possible complexity of the downstream conditions relating to energy dissipation, it is essential that the design of all but the smallest structures is verified with hydraulic physical model tests.

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[10] Appendix V Structures to assist fish migration through major obstructions such as dams and weirs.

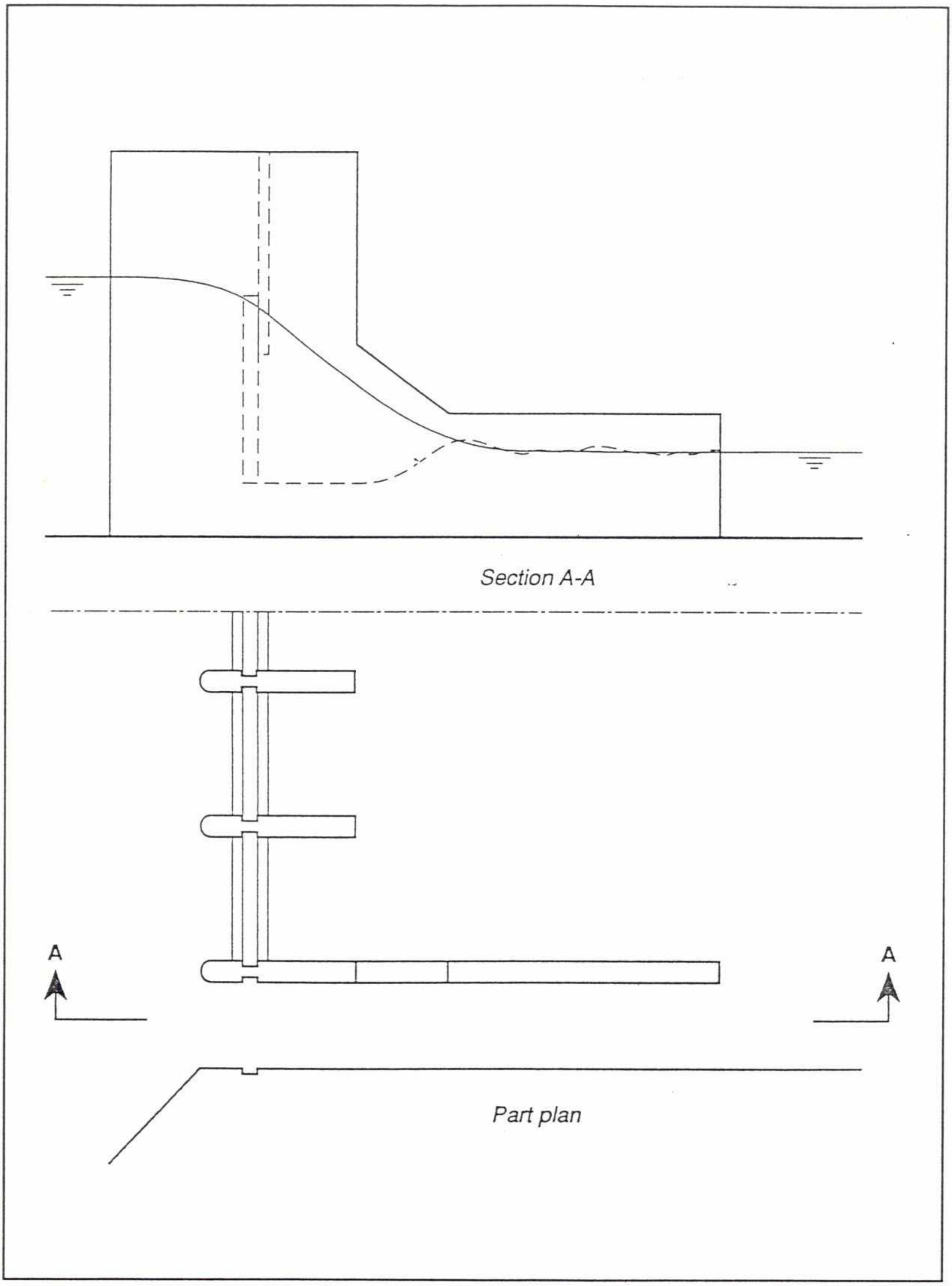

Figure 17 Gate detail

Appendix I

Classification of Migratory Fishes

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Classification of Migratory Fishes

As an attempt to clarify the seemingly complex range of observed migratory patterns, various classification systems have been devised by several authors. Categorisation appears to be based upon either the movements made or types of migrant fish.

1. Classification of Fish Movements

By combining categories identified and discussed by Daget (1952, 1960) Johnels (1954), Blache et al (1964), Williams (1971) and Welcomme (1985) it appears that 3 distinct components of migration, applicable to all flood rivers, can be identified.

1. LONGITUDINAL MIGRATIONS (within main channels)	A. UPSTREAM B. DOWNSTREAM
2. LATERAL MIGRATIONS	A. FROM MAIN CHANNEL TO FLOODPLAIN B. FROM FLOODPLAIN TO MAIN CHANNELS
3. LOCAL MOVEMENTS	A. ON FLOODPLAIN AND WITHIN FLOOD SEASON HABITATS B. WITHIN DRY SEASON HABITATS (eg main channels, adjoining lakes) and river systems, river mouth, ocean

A second classification is suggested by Whitehead (1959) based on the fishes of Lake Victoria, Africa: Potamodromous migration may also be categorised:

Long Duration	-	C > 50-80km upstream eg Barbus altianalis
Medium Duration	-	C 25km upstream, often in compact shoals eg Labeo victorianus
Short Duration	-	< 8km sudden and shortlived, often in large shoals (Welcomme 1969) eg small Alestes.

2. Classification of Types of Migrants

Based on observations of fishes of the Mekong River system (South East Asia) two broad categories may be identified:

A. "Whitefishes"	-	generally considered to cover greater distances and make extensive migrations between wet and dry season habitats.

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- migrate upstream in the dry/early wet season
- feed on plankton and small fishes
- generally migrate by day
- are generally fluvial
- eg most cyprinids

B. "Blackfishes"

- believed to migrate only locally within the floodplain and show restricted movements between wet and dry season habitats: maximum movements (lateral and local) are made between flooded are and fringes of the main channel, or from dry season residual pools of the floodplain to the flooded area.
- feed on benthonic organisms
- generally migrate by night
- tend to be bottom-dwelling
- eg. many siluroids

A second classification is based on the seasonality of reproduction (Lowe-McConnell 1975) and thus excludes the few "big bang" spawners, which spawn only once during their life-cycle. Of the many species which show repeated spawning at intervals ("multiple spawners") two categories may be identified:

A. Total Spawners

- often make extensive migrations, on a seasonal basis, to and from upstream spawning ground and also into the floodplain.
- migrations coincide with the floodcycle; rains appear to initiate spawning in some way.
- tend to have high fecundity with well defined breeding seasons; ova ripen all at once, numerous small eggs are released in one batch per season and are usually timed so as to be hatched at the most optimum stage of the flood cycle.

- common amongst fishes of the Polamon
- includes piracema fishes and large characoids Prochilodus and Salminus.

B. Partial (or "Serial" or "fractional") Spawners

- tend to make only local migrations; tend not to move upstream but make lateral movements within the floodplain
- less dependent upon floodcycle, but often spawn and breed just prior to the wet season
- breeding seasons generally ill-defined; only some ova ripen at one time, but are shed at frequent intervals; larger sized egges are released in several small batches; parents tend to quard eggs and exhibit territorial behaviour.
- common amongst fishes of the rhithron; often smaller-sized (fishes with shorter life span)
- eg Hoplias malabarbicus, many cichlid eg Osteoglossum and loricariid catfishes and cichlids.

Based on analysis of fishes the Chad Basin, Africa, Carmonze et al (1983) distinguishes 3 groups of migrants as:

A. True Migrants - those that make long-distance longitudinal movements for breeding eg Alestes baremoze and Labeo senegalensis

B. Mixed Migrants - includes adults and juveniles

C. Lateral Migrants - those that make movements between the main channels of the river and the floodplain. Movements are associated mainly with feeding.

As a general rule, the larger (and) therefore stronger-swimming) fishes undertake more extensive migrations than do the smaller-sized species.

Appendix II

Regional Appraisal of Migratory Patterns

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Appendix II

Regional Appraisal of Migratory Patterns

1 Africa

A Rivers

i) Chari-Logone River Systems

- **Alestes baremoze:** during low water migrates upstream to the Yaeres floodplain to arrive at this important feeding ground at the onset of the floods (Welcome 1895).

- Some Lake Chad fishes which remain in the lake during highwater migrate many hundreds of kilometers upstream into the Chari-Logone floodplain as waters rise (Blacke & Miton 1962).

- During high-water, fishes are widely dispersed in the inundation zone (October), and return to the main channel as water levels fall during December to February (Lowe-McConnell 1955).

ii) Niger River System

- The inundation zones of the Central Delta and mid-Niger form the main breeding and feeding grounds. In the mid-Niger Brycinus spp and Alestes leuciscus, au migrate 125km - 400km up river at maximum speeds of around 9km/day (Daget 1952), (this incidentally, was prior to the construction of Markala Dam).

- Spawning tends to occur as water rise since the wet season coincides with the warm season, which tends to increase the rate of development of juveniles (Lowe-McConnell 1975).

iii) Zaire River System

Most fishes migrate upstream as waters begin to rise. As flooding begins, lateral movements into the floodplain are made. Exceptions to the this general trend include: clupeids, cyprinids, schibeids and certain pelagic species, (Lowe-McConnell 1975; Matthes 1964).

iv) Zambezi River System

- The central Barotse forms the main floodplain and fishery of the river.

- For many species (except for example, cichlid Serranochromis macrocephalus, which spawns in October) spawning is timed prior to high-water, from December to March.

- Up-river spawning migrations begin at the onset of rains (December). Most young are hatched during the flood season. These longitudinal migrations are followed by lateral migrations onto the floodplain then later withdrawal back to the main river channel as the rains cease (April), with young-of-the-year tending to migrate back in May and June (Lowe-McConnell 1975).

v) **Senegal River System**

- Lateral and vertical migrations of distances of up to 400km have been observed for migrating species, which include: Alestes, Brycinus, Citharinus, Distichodus, Labeo, Lates and Clarias (Reizer 1974).

B Fishes

- Main migratory species are characins, some siluroids and certain cyprinids.

- Non-piscivorous characids eg Alestes baremose and A.dentes may migrate considerable distances up river to spawn.

2 South America

A Rivers

- The rivers of South America show perhaps the most spectacular, and best-documented migrations of the world. Similar patterns have been observed for many moderate-sized rivers (eg, for rivers Maderia (Goulding 1980), Rupununi (Lowe-MacConnell 1964) Sao Francisco (Paviva & Bastos 1982) and Pilcomayo (Bayley 1973) which are presumably repeated, for similar fish populations or species, throughout the continent.

i) **Rio Maderia:**

- Characins (eg Prochilodus and Brycinus species) make upstream migrations, at the start of floods, to spawn in the headwaters. These return downstream, to feeding grounds, later in the season (Goulding 1980). Species which do not undertake upstream spawning migrations may move the lakes or flooded forest areas to spawn (Lowe-McConnell 1975).

- Early foods: fishes move down tributaries to spawn in the main river (November to December).

- High water: "spent" fishes move back up with tributaries, often in small groups, to floodplain area to feed and grow for several months.

- Early dry season: fishes return down tributaries to the main river

- Low-water: fishes move intermittently upstream of the main channel (before

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re-entering upstream tributaries as waters start to rise). Older fish tend to move furthest upstream.

- Piracema migrations upstream are also observed (Section 2.2.2)

ii) Mogi-Guassu River System

- Piracema migrations (section 2.2.2) are well-documented. Spawning migrations upstream begin at the start of floods (September to November) (Godoy 1975).

- 17 characin species each year migrate between downstream potamon floodplain feeding sites and upstream rhithron spawning sites, a distance of around 1230km.

- Schools of up to 80,000 individuals of Prochilodus scrota have been observed migrating upstream (eg Godoy 1954).

iii) Magdalene River System

- Distances of up to 500km separate upstream breeding sites and downstream feeding areas.

- Two seasons of activity have been observed for certain species such as Prochilodus reticulatis (Welcomme 1985).

  1. A major "subienda": fishes migrate upstream in February and March, and return downstream in April and June

  2. A minor "mitaca": fishes migrate upstream during July to september and return downstream October to December.

iv) Parana & Uruguay & Paraguay River Systems

- Movements of fishes have been examined by Bonetto & Pignatben (1964) and Bonetto et al (1971; 1981).

- Some large characoids migrate distances of up to 1400km between feeding and spawning sites.

- Salminus maxillosus: migrates downstream of the Parana in October

- Luciopimelodus pati: migrates up to 600km upstream to spawn. Timing of upstream migrations coincides with **falling** water levels. Of particular interest, male fishes tend to remain up-river for increasing lengths of time as they grow older, thus downstream populations are dominated by females.

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- **Pilcomayo River** (tributary of the Paraguay River):

- For most large fishes, the Lower Chaco Swamps in the main floodplain feeding area. After feeding, many fishes (eg Prochilodus platensis, Leprinus obtusidens, Colossoma mitrei, Salminus maxillosus, Schizodon fasciatum migrate to upstream Andean reaches to spawn; spawning runs tend to reach a maximum intensity during July and August each year. These breeding and feeding grounds are separated by a distance of approximately 450km (Bayley 1973, Lowe-McConnell 1987)

- At the onset of floods (November & December) return migrations are made towards the downstream floodplain area for feeding (Bayley 1973).

v) **Rupununi River, Guyana**

- At the onset of rains, many characoid and other species eg Myleus pacu begin upstream migrations; others eg, Cichla ocellaris move laterally into the flooded savanna. Most species show well-defined breeding seasons coincident with the main rains (Lowe-McConnell).

South America

B Fishes

- Similar migratory patterns for characin spp have been observed in: Rio Pilcomayo, (Bolivia) Rio Mogi-Guassu (Sao Paulo) and La Plata system (Bayley 1973; Godoy, 1967; Bonetto & Pignalben 1964; Bonetto et al 1971).

- The complex movements of Prochilodus spp are well documented, since these are of significant importance to local fisheries. An estimated 200 million or more P.platensis individuals, from populations of various areas, gather in the "summer" in Rio de la Plata but break up in the winter (February to March) (Ringulet et al 1967), after which some migrate up River Uruguay whilst others migrate up River Parana (Lowe McConnell 1975).

- Salminus maxillosus (dorado) is a regular migrant in the Rio de la Plata, Amazon, Parana and Pilcomayo rivers. Spawning runs up the Mogi-Guassu River During rising water (October and November) have been observed (eg Lowe-McConnell 1975).

Asia

A Rivers

i) **Amur River System**

- Ctenopharyngodon idella and Hypophthalmichthys molitrix move up to 1,200km from downstream feeding grounds to upstream spawning sites (Krykhtin & Gorback 1981)

ii) **Ganges River System**

- Torr spp. undertake extensive migrations from the floodplain to major tributaries of the Himalayas (Welcomme 1985).

iii) **Tigris & Euphrates River Systems**

- Several cyprinid species (eg Barbus xanthopterus, B.grypus and Aspius vorax) migrate upstream to gravel bed spawning sites during early spring floods. Juveniles later drift downstream to flooded areas. (FAO/UN 1954).

iv) **Mekong River System**

- Scale of migrations is said to be large with pathways up to 1,000km (Shiraishi 1970) eg Pangasianodon gigas (giant catfish) (Lowe McConnell 1975)

- Migrations have been observed fro eg Pangasianodon gigas
  P.parigisus
  P.sutchi
  P.sanitwongsei
  Cirrhinus auratus
  Probarbus jullieni
  Thynhicthyes thynoides
  T.vaillanti

- P.sutchi: moves 300km-400km from Grand Lac to Khone Falls (Bardach 1959).

- T.vaillanti: migrates C 450km between wet and dry season habitats (Saanin 1953).

- Generally believed that upstream migrations begin as water levels rise, and fishes return at the start of the dry season as water levels fall.

- Upstream migrations into inundated areas during high-water are generally for spawning and breeding; during the dry season, mainly fishes congregate in the Grand Lac and Quatre Bars area (Shirashai 1969).

- As levels of water rise within the Tonle Sap and Grand Lac, fishes move into the lake then laterally out onto the floodplain. At the end of the rains (October - February), fishes return downstream to the lake and down the main river (Chevey and Le Poulain 1940; Le-Van-Dang 1970).

- Pack spawning occurs as waters rise (June and July), diminishes as waters fall (March) and virtually ceases during low-water (April and May) (Lowe-McConnell 1975).

iv) Indus River System

Anadromous migrations are made by Hilsa ilisha, which are said to enter the mouth and proceed up-river in Mid-January and return downstream during July to August with a peak in April and May (Islam & Talbot 1988).

Asia

B Fishes

- Large-bodied cyprinings eg big head carp Aristichthys nobils often spawn pelagic eggs in the river which are then swept downstream to the nursery areas along the flooded fringes of the river (Wootton 1992).

- Probarbus jullieni undertake long distance spawning migrations in the Mekong (Srit & Yoov 1977).

- Migration made by fishes of major Indian rivers have been reviewed by Day (1958).

- Catla catla : spawn once a year, generally at night
  : appear to ascend rivers to spawning grounds during the monsoon rains
  : said to be local migrants, undertaking only short limited journeys but travel further afield during the rains to spawn (Jhingran 1968)

- Labeo and Cirrhinus Mrigal and Rohu: also said to be local migrants, undertaking short journeys to suitable spawning sties (Jhingran & Khan 1979; Khan 1975).

- Hilsa ilisha:

- Day (1873) and others suggest this species is anadromous in the Genetic rivers, spending part of life cycle in the sea. Other authors may doubt this. The distances covered by these river migrations, and their timing are subjects under discussion. Distance covered are probably not as great as originally believed, and it is probable that the River Ganges has more than one stock, each making complex movements such as more than one spawning run each year.

- During upstream migrations, individuals of this species are said to 1) congregate in small groups and 2) form large groups and rise to the surface on meeting obstructions to the migratory pathway eg dams (Pillay & Rosa 1963).

Appendix III

Critical flow

Appendix III

Critical flow

Critical flow has a number of properties but the most important physical feature is that the velocity of critical flow is equal to the velocity of a wave of low amplitude in that depth of water. Such a wave would therefore appear to be standing still. If the flow velocity was higher than critical (supercritical flow) the wave would be swept downstream but when the flow velocity was lower than critical (subcritical) the wave would travel upstream.

In practical terms, this means that if the flow from a regulator gate is supercritical, the flow is not influenced by any feature downstream. Moreover, the change from supercritical flow to the subcritical flow in the river downstream will be abrupt, creating a 'hydraulic jump' that is accompanied by considerable turbulence and energy loss. The stilling basin of a regulator can be designed to induce the 'hydraulic jump' to deliberately dissipate energy in a short distance and thereby protect the channel bed and banks further downstream. It is the energy dissipation downstream of a regulator that is considered to be one of the more damaging features of a regulator in relation to the passage of fish.

Appendix IV

Structures for the Compartmentalisation of the Tangail Area (Flood Action Plan 20)

Appendix IV

Structures for the Compartmentalisation of the Tangail Area (Flood Action Plan 20)

1 Introduction

The proposed compartmentalisation of the area around Tangail required one large structure will be at the head of this river at Krisnapur Jugini. Some peripheral areas more remote from the Lohajang will be fed by smaller structures from the Gala Khal, the Pungli river and the Dhaleswari river. At present it is not proposed to regulate the flow of the Lohajang river out of the area.

2 The Krisnapur Jungini regulator

This is the main regulator for the scheme and is sometimes referred to as the Lohajang Regulator.

The initial dimensions of the regulator were a width of 12m and a sill level of 9.5 mPWD (metres above Public Works Datum). The sill level is the current level of the river bed at the regulator site. An estimation of the performance of the regulator was carried out by FAP 20 engineers using the MIKE 11 numerical river model. Main river levels upstream of the regulator and rainfall within the compartment were derived from data from 1991 for the purpose of these runs.

2.1 Results of Trial Runs with the MIKE 11 Numerical Model

The first results were made available before the site visit to Bangladesh. Sections 2.1.1 and 2.1.2 summarise these results. Further sections describe runs made during the site visit.

2.1.1 Initial run with gates

Figure A1 shows the imposed upstream level and the calculated downstream level with a gate regulator. The gate control programme for this run specified that the gates be closed when the level upstream of the regulator exceeded 11 mPWD. The broad aim was to control level in the compartment at 11 mPWD which corresponded to a flood area coverage in the compartment of approximately 50 percent.

Shutting the gates at an upstream level of 11 mPWD meant that the gates were shut for the greater period of the flood while the level inside the compartment varied due to the combination of rainfall within the compartment and drainage into the lower Lohajang. This scheme resulted in a variable compartment level rarely rising above 10 mPWD and access for fish hatchlings limited to the first half of June. Since fish fry may be on the move well into August, this was not a satisfactory control programme from the point of view of fish capture nor for close control of the compartment level.

2.1.2 Initial run without gates

An alternative operating scheme using the structure as an uncontrolled throttle gave a pattern of compartment water level against time shown in Figure A2. It can be seen that compartment water level reflected the peaks and troughs of the upstream hydrography to give an average level close to 11 mPWD.

With regard to the effect on fish capture, this method of operation is favourable since the there is flow through the structure at all times and the free surface, full depth flow has least disbenefit to fish fry in terms of pressure changes and turbulence.

2.1.3 Test run with 24m wide regulator

The deliberate restriction of the discharge into the compartment will limit the total fish capture but if the concentration of fish fry approaching the mouth of the Louhajang is greater near the bank, as is generally assumed, the reduction in fish capture will not be as great as the reduction in discharge. However, the reduction in discharge relative to that in the unregulated river will be greatest monsoon which is also the time when the evidence is that the greatest concentration of fish fry occurs. To limit reduction of fish capture at this critical period, the regulator would require greater capacity ie: greater width since the sill is already as low as it can be set. FAP 20 were therefore requested to run a test on MIKE 11 for a regulator with a width of 24m, twice the original width.

The result is shown in Figure A3. It can be seen that during the first rise in the monsoon hydrography, there is very little head loss across the structure indicating that the discharge is close to that of the natural river and fish capture would not be much reduced. This test was also run with a gate control programme that closed the gates when the upstream level exceeded 11 mPWD. As before, the gates would be closed during most of the remainder of the flood hydrography. The downstream water level was closed to 11 mPWD when the gates closed and this level was generally maintained by rainfall within the compartment.

2.1.4 Test run with gates fully open or fully shut (1)

The much larger structure and the rapid rise in compartment level at the start of the monsoon did not suit FAP 20 requirements and no further tests were carried out on a 24m wide structure. The system of controlling the gates with reference to the upstream level downstream was influenced by the shape of the upstream hydrography and rainfall within the compartment and therefore not predictable from year to year. FAP 20 were therefore requested to run further tests with gate operation controlled by the downstream level.

At this time it was becoming clear that, where possible, free surface flow was the preferable mode of operation for fish passage if it could be achieved. FAP 20 therefore ran a test in which gates were either fully open or fully shut. In this way, flow area was varied by changing the width only and flow through the open sections of the regulator was always free surface.

The operating sequence used was:

Gate opening %	Downstream water level while - Closing	Opening
0	11.5	11.1
5	11.1	10.9
20	10.9	10.6
50	10.8	10.3
100		

The downstream water level pattern obtained with the gate control programme is shown in Figure A4. Regulation was clearly not ideal for the following reasons:

i) The open area could be changed only in relatively coarse steps so that fine regulation was difficult. The computer employed percentage openings but in practise the percentage would depend on the number of openings; the fewer openings, the coarser the control. This system would not therefore be applicable to small regulators.

ii) When a change was made, the characteristic that discharge rises at a faster rate than upstream water level and vice versa caused fairly rapid changes in the controlled level that would call for frequent gate changes to maintain a reasonably steady level.

iii) Combination of the two features above could cause a hunting effect that would make smooth regulation particularly difficult.

2.1.5 Test run with gates fully open or fully shut (2)

Before revising the method of operating the gates another test was run to see how the gate operation method used in the previous test performed at a higher controlled level of 11.8 mPWD. The gate operation programme is shown below.

Gate opening %	Downstream water level while - Closing	Opening
0	11.5	11.1
5	11.1	10.9
20	10.9	10.6
50	10.8	10.3
100		

The downstream water level pattern obtained with this gate control programme is shown in

Figure A5. Again the control was relatively poor.

2.1.6 Combined gate tests

Analysis of the characteristics of different methods of gate opening (see main text) indicated that when the downstream water level reached a level where gate control was required, undershot gates would be the preferable method but that a section of the regulator should have free surface or overshot flow for fish passage and this section should operate continuously if possible.

The MIKE 11 numerical model was not able to calculate the performance of a regulator with a combination of undershot and overshot gates and the feasibility of this method could not therefore be tested in detail.

2.1.7 Final test with undershot gates

The gate control programme for this test was changed by FAP 20 to one that responded to head difference across the structure:

Head difference (m)	Position of gate mPWD
0.0	12.55
0.1	12.55
0.5	12.00
0.6	11.85
0.7	11.30
1.0	11.00
1.5	10.00
2.0	9.80

The operating programme also stated that the gates would be fully open to the end of June to facilitate fish passage. Figure A6 shows the discharge curves provided for the structure fully open and as controlled. It can be seen that the gate control clips the peaks of the hydrography and in fact has done so in June. The pattern of water level with time downstream (Figure A7) was very similar to that shown in Figure A2 for an ungated structure although maximum level in June and August was slightly higher.

Inspection of the water level plots in relation to the gate operating programme shows that during the period from the water level first rising above the sill to the end of August when most of the fish fry will have passed by, the gates would be more than 50 percent open for 82 percent of the time and above water level for 44 percent of the time (53 percent if the gates are left open make the structure basically fish-friendly but the remaining 18 percent of the time is a period of approximately 12 days in the middle of July when the gate opening is only one seventh of the water depth or less. This condition would be a threat to fish fry which would still be on the move in quantity and the design would be improved if one or both of the outer gates was designed to allow overshot flow during the time when the main gates are closed this far (reference Section 2.1.6).

2.1.8 Energy dissipation downstream

When the downstream level is controlled at 11 mPWD, the depth of water above the bed is only 1.5m. The stream from the regulator is confined to a width of 12m and dissipation of energy in these conditions will be a severe problem. It is unlikely that a hydraulic jump can be formed unless a deep stilling basin is introduced and unless the basin is expanded to considerable width at the outlet, velocities at the outlet of the basin would still be dangerously high. Limited calculations that can be done at this time suggest that an apron at bed level with a high surface roughness (cross bars for example) might be an alternative and this method would appear to be less stressful to fish in passage. A controlled expansion of the flow downstream would still be required. Whatever method issued to dissipate energy, extended bed protection downstream to a distance of at least 50m will probably be necessary. The three dimensional flow in an expanding outlet cannot be predicated with sufficient accuracy and a physical model investigation of this structure must be made.

2.2 Summary

The final gate control programme tested gives a situation where the regulator is comparatively fish-friendly but relates only to the particular upstream hydrograph and downstream controlled level. It is not therefore predictably fish-friendly under all circumstances and should have one or two of the outer gates arranged for continuous overtopping flow whenever the main controlling undershot gates are closed down to less than 50 percent of the upstream depth.

There are some anomalies in the data available in that the regulator appears to give the specified downstream level without any gate control; in fact, the calculated downstream levels appear to rise a little when gate control is applied.

It is intended that the controlled level in the compartment should be variable to give optimum conditions for agricultural production and levels up to 11.8 mPWD have been mentioned. It should be noted that in the initial run (Section 2.1.2) when there was no control other than the width of the structure, the average level in the compartment did not rise above 11 mPWD. it therefore appears that levels above this are unlikely to be reached unless the flood is bigger than that used in the test runs, the Krisnapur Jugini regulator is widened or a control is placed on the Louhajang at the downstream end of the compartment.

3 MINOR STRUCTURES

3.1 Shadullapur Regulator

This regulator has two undershot openings 1.52m wide by 3.05m high set on a sill at level 9.5 mPWD. The proposed gate operating programme is shown below. An additional proviso is that the gates will be left open throughout June for fish migration.

Head difference(m)	Position of gate mPWD
0.0	11.33
0.1	11.33
0.4	11.00
0.5	10.60
0.65	10.41
0.8	10.00
1.0	10.00
1.2	9.85
1.6	9.50
2.0	9.50

The upstream hydrograph and the downstream level against time is shown in Figure A8. The control programme gives average downstream level at around 10.5mPWD as against the projected level of 11 mPWD. Inspection of the water level plots in relation to the gate operating programme shows that during the period from the water level first rising above the sill to the end August when most of the fish fry will passed by, the gates would be above water level in the first half of June and briefly at the being and end of July. In the second half of June and the middle of July, the gates would be shut completely and would have very small openings during the rest of the period. There was some disagreement between this assessment and the supplied discharge curve which, for example, showed no discharge at all before the end of June. However, on either reading this structure is very inhibiting to safe fish passage when controlling the level at or about 10.5 mPWD and for a large part of the period is impassable.

In principle, one of these gates should allow overtopping flow to maintain a small flow over most of the monsoon period, possibly a narrower gate allowing the other wider undershot gate to do the major part of the flow control (see main text). Ideally, the options of gate size, type and operating sequence should be tested on the MIKE 11 model. However, since it appears that the model may have difficulty in simulating compound gates, an alternative method would be to first determine the gate flows with time that give the required downstream water level using any type of gate and control programme. A desk study of alternative gate sizes and types that gave the same discharge pattern could be made.

3.2 Rasulpur Regulator

This is a small single gate regulator 1.52m wide set on a sill at a level of 9.22 mPWD. An assessment of the regulator relates the water levels, gate control programme and discharges to each other. The data available for this regulator shows a major anomaly in that the maximum discharge occurs when, according to the control programme, the gate would be shut. It is therefore not possible to make an meaningful assessment of this regulator.

3.3 Jugini Regulator

This regulator has a single vent 1.52m wide and a sill level of 10.62 mPWD. The gate control programme is shown below and is designed to maintain a downstream level of 12 mPWD.

Heading difference (m)	Position of gate mPWD
0.0	12.45
0.1	12.45
0.5	12.45
0.6	11.7
0.7	11.53
1.0	11.20
1.5	11.0
2.0	10.62

The upstream input hydrograph and the calculated downstream level are shown in Figure A9. Average downstream level is approximately 11.5 mPWD. Relating the gate operating programme to the water level profiles indicates that the from the moment of spilling over the sill to the end of August, the gate would be above water level for 46 percent of the time and the gate opening would be at least 50 percent of the upstream depth for 85 percent of the time. this result makes the regulator comparatively fish-friendly and comes about because the downstream level is being controlled at a higher level than the other regulators listed which requires that the gate is open for a greater length of time. when the operating programme is refined to move the downstream level closer to the 12 mPWD specified, this situation will improve further. However, the small gate opening that would be most detrimental to fish in passage occurs in the middle of July when concentration of fish fry may still be high. A two part gate that would allow controlled overflow as well as underflow would provide as fish-friendly a structure as is possible with only one gate opening.

3.4 Summary

In general, these small regulators are not very fish friendly if using only one or two undershot gates because the gates are likely to be closed down to very small openings or shut entirely during the period when fish fry are on the move. If the width of the regulator is chosen such that it controls at close to the required level without gate control then it will obviously be much more fish friendly. As it stands, the Jugini regulator is relatively fish-friendly because it is being controlled at a downstream level that requires discharges close to the full capacity of the opening. However, this situation applies only to the particular downstream level and upstream hydrograph chosen for the trial run. To make the regulators adaptable to different patterns of upstream and downstream levels, one of the gates should be passing some discharge, however small, through the period when fish fry are on the move.

4 Conclusions

a) The various structures required to control flow into the Tangail compartment require undershot gates for main control but eh degree to which they inhibit fish fry movement is dependent on the required level downstream and the upstream hydrograph pertaining to a particular monsoon season. For minimum restriction to fish fry movement and least damage to the fr in passage, all the regulators should have provision for free surface flow through at least one gate during the whole of the migration period. If this is too restrictive a stipulation, free surface flow should be available whenever the main gate opening is less than 50 percent of the upstream depth.

b) The gate operating procedures should be refined using the MIKE 11 numerical model. the present range of hydrographs and operating procedures tested is limited and available discharge data appears to indicate that the regulator gates are not always being left fully open throughout June as stipulated. However, the model is apparently unable to handle a mixture of gate types in one regulator. Nevertheless, the model should be used to establish regulator discharges necessary to maintain the required compartment levels for a typical range of upstream hydrographs. Some anomalies appear in the data supplied by the MIKE 11 model in relation to the operation of structures which may arise from the transition between the different equation used for flow under a gate and for free surface flow through a fully open vent or from the use of downstream natural river sections wider than the outlet of the regulator.

c) To offset the potential limitations of the overall numerical model in dealing with detail at structures, it would be advantageous to carry out a desk study of gate control programmes using a combination of undershot and free surface flow gates based on the water levels and required discharge derived from the MIKE 11 model. The regulator designs should be physically model tested with particular reference to safe dissipation of energy downstream.

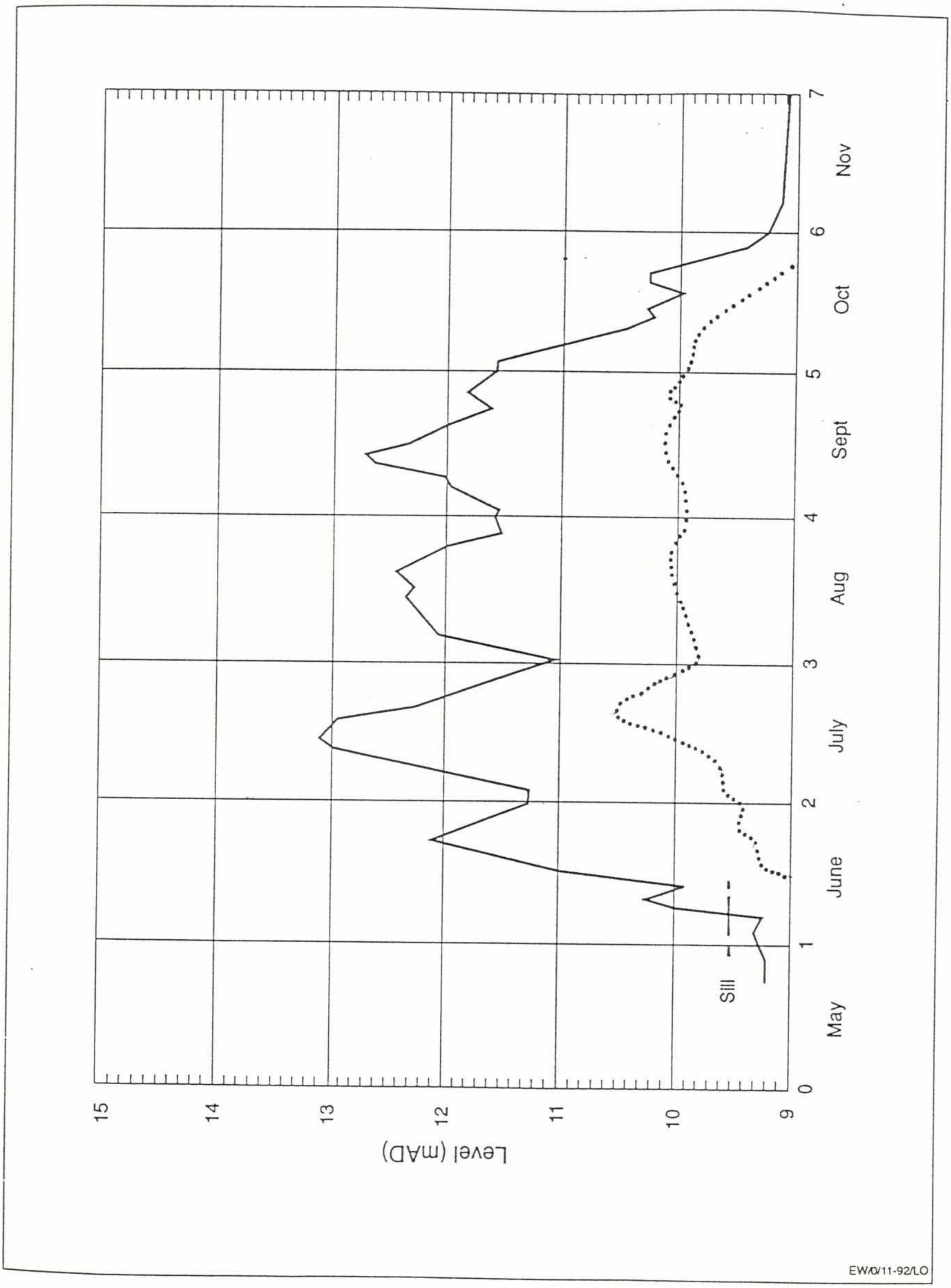

Figure A1 Krisnapur Jugini Regulator - upstream control

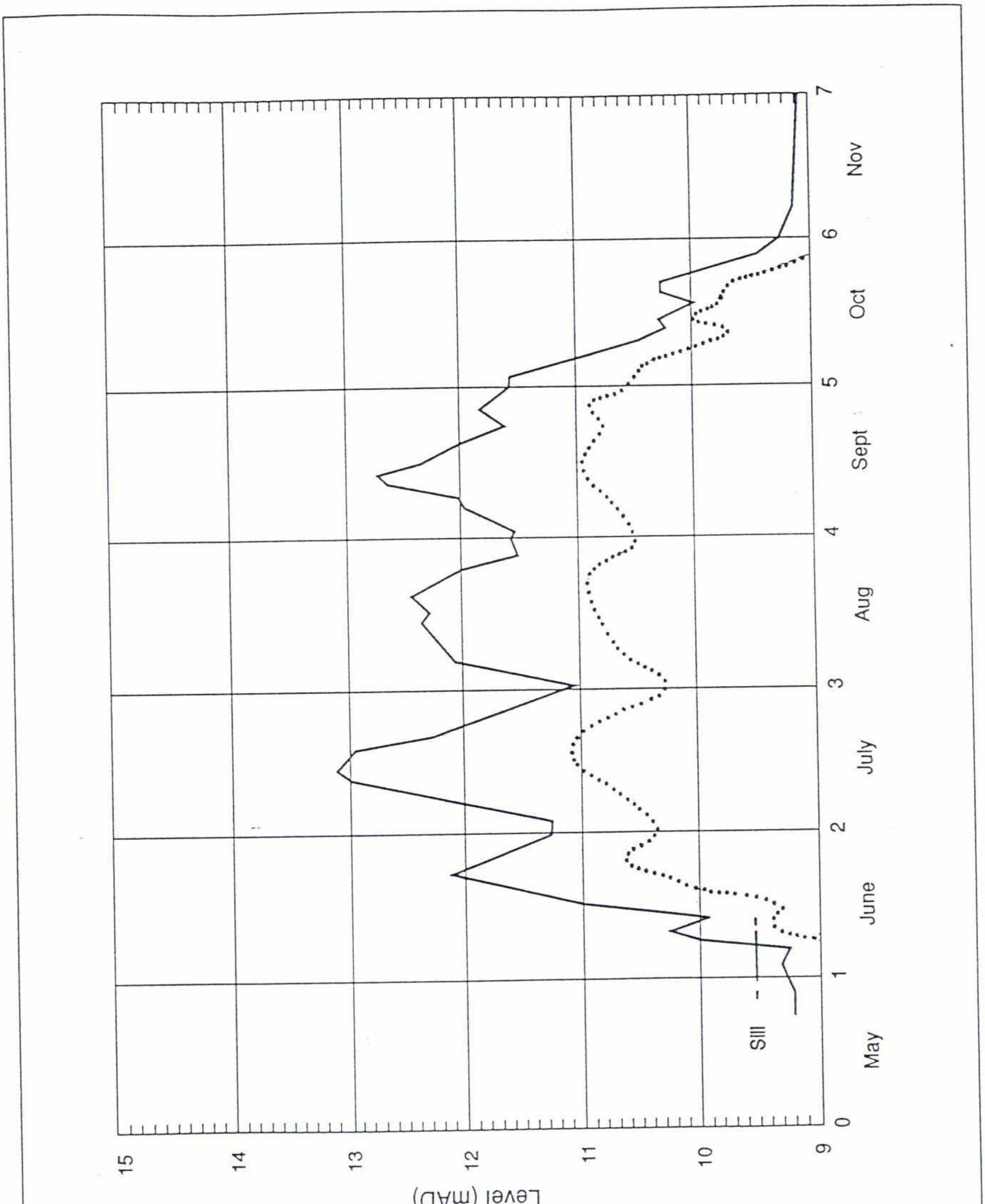

Figure A2 Krisnapur Jugini Regulator - ungated

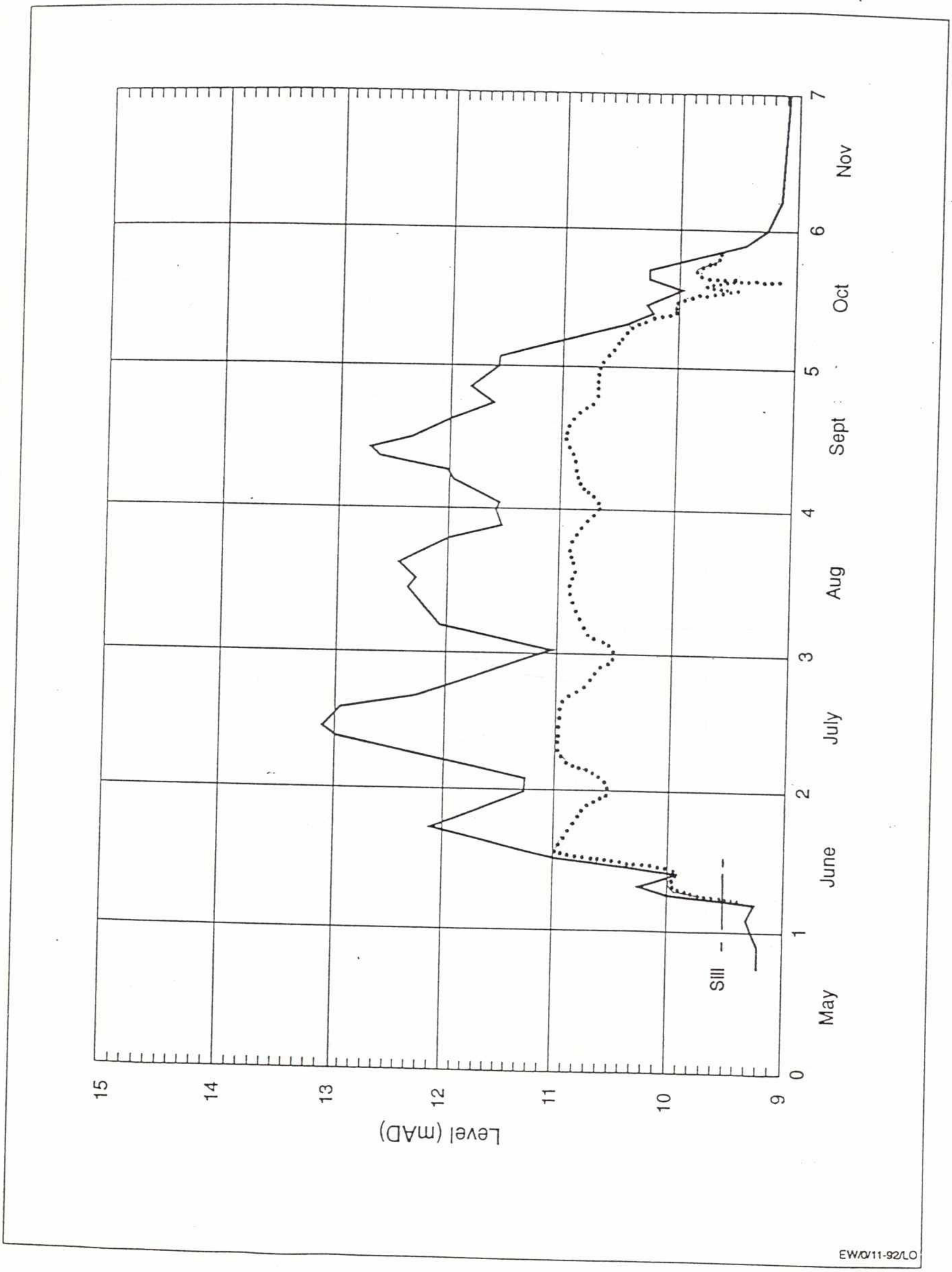

Figure A3 Krisnapur Jugini Regulator - upstream control - 24m wide

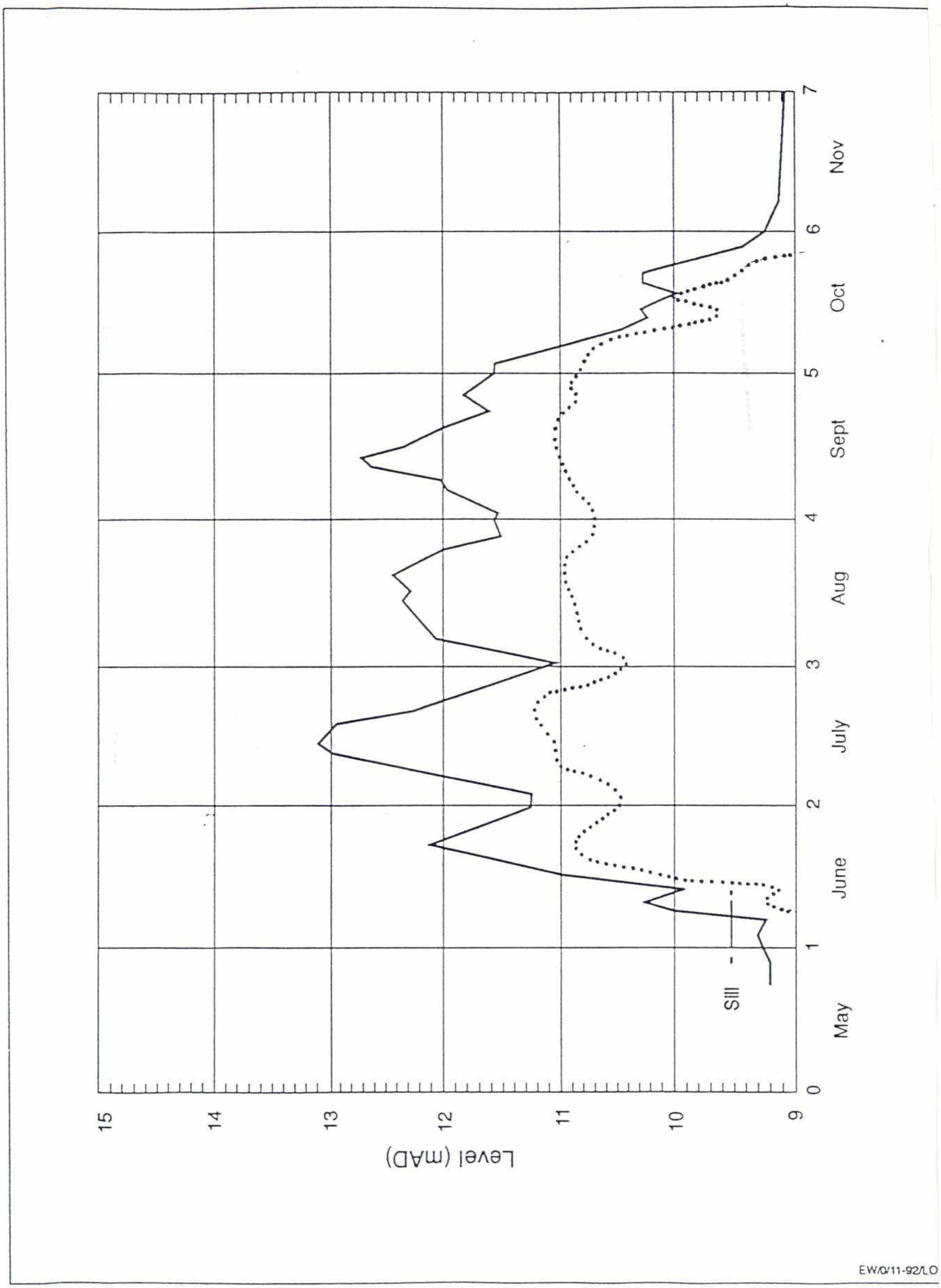

Figure A4 Krisnapur Jugini Regulator - downstream control (11mAD)

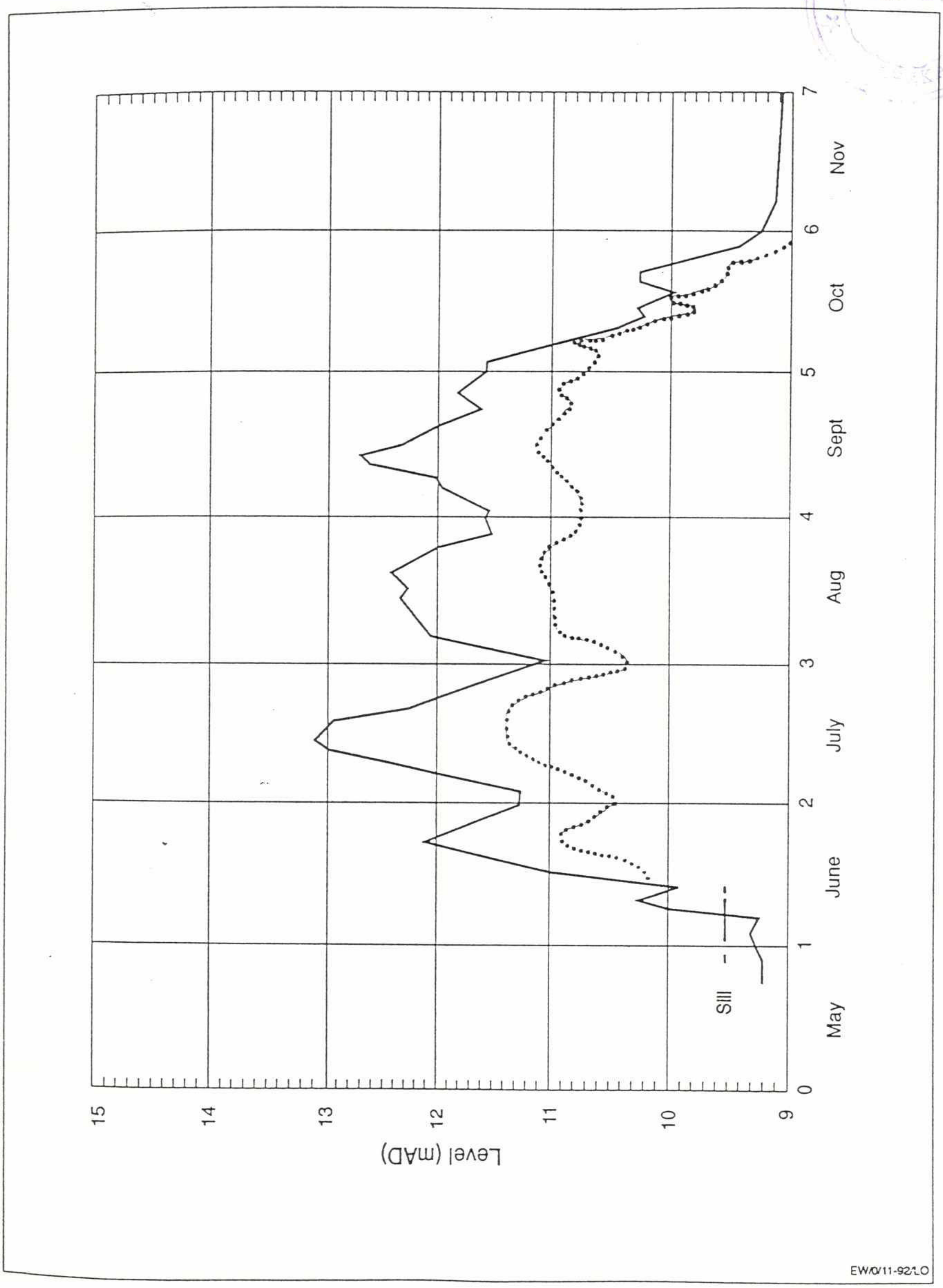

Figure A5 Krisnapur Jugini Regulator - downstream control (11.8m AD)

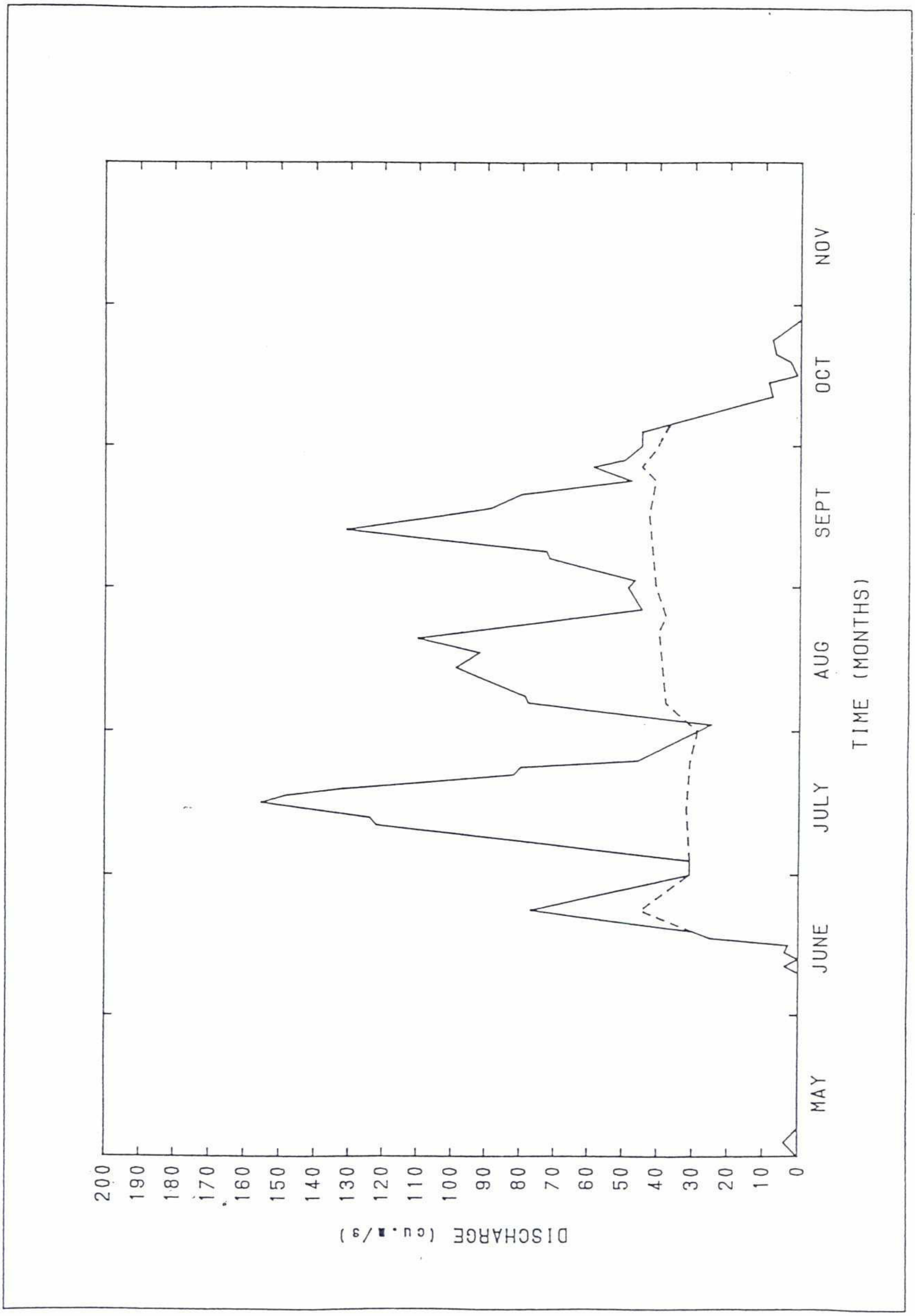

Figure A6 Krisnapur Jugini Regulator - ungated discharge and controlled discharge

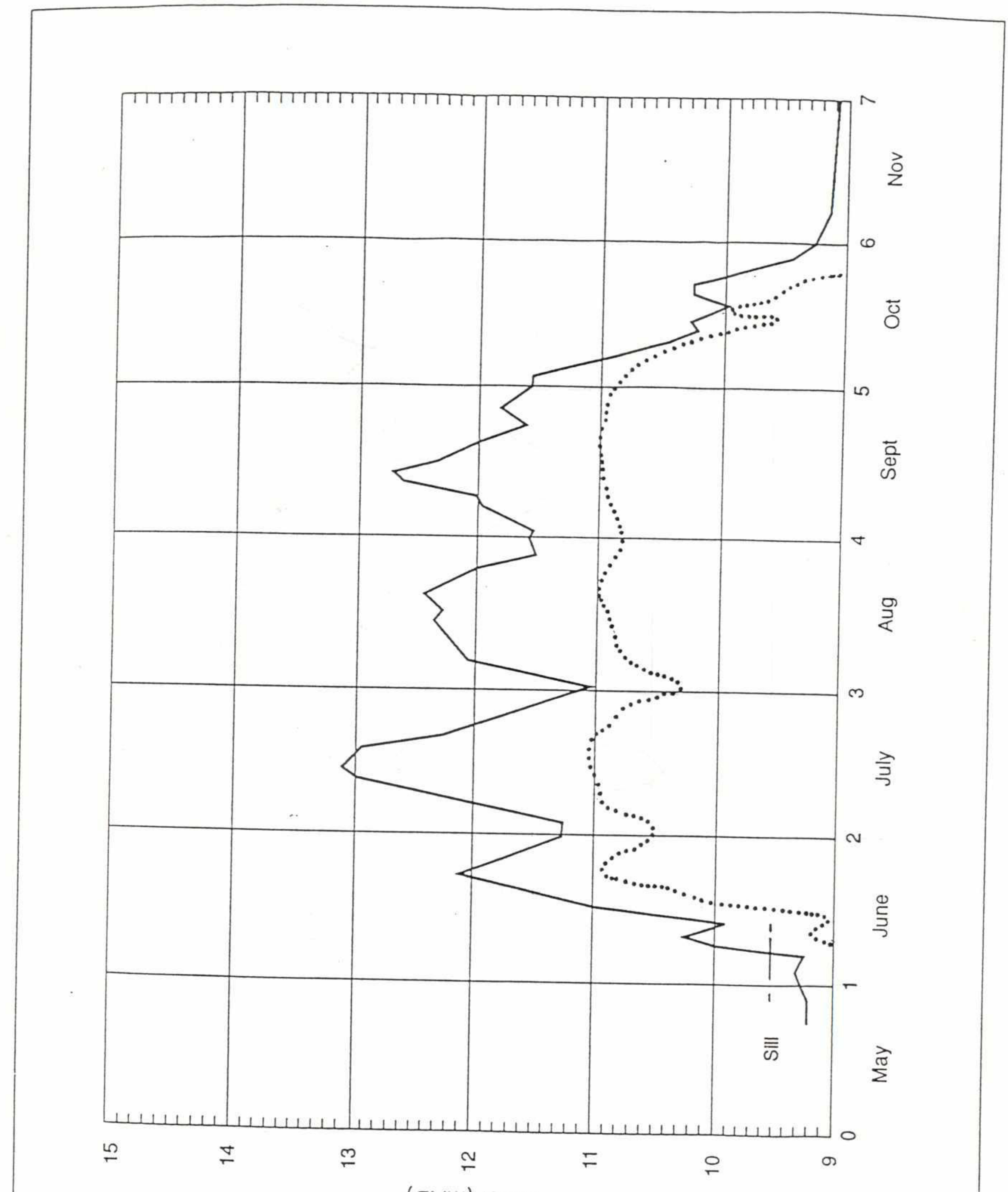

Figure A7 Krisnapur Jugini Regulator - level difference control

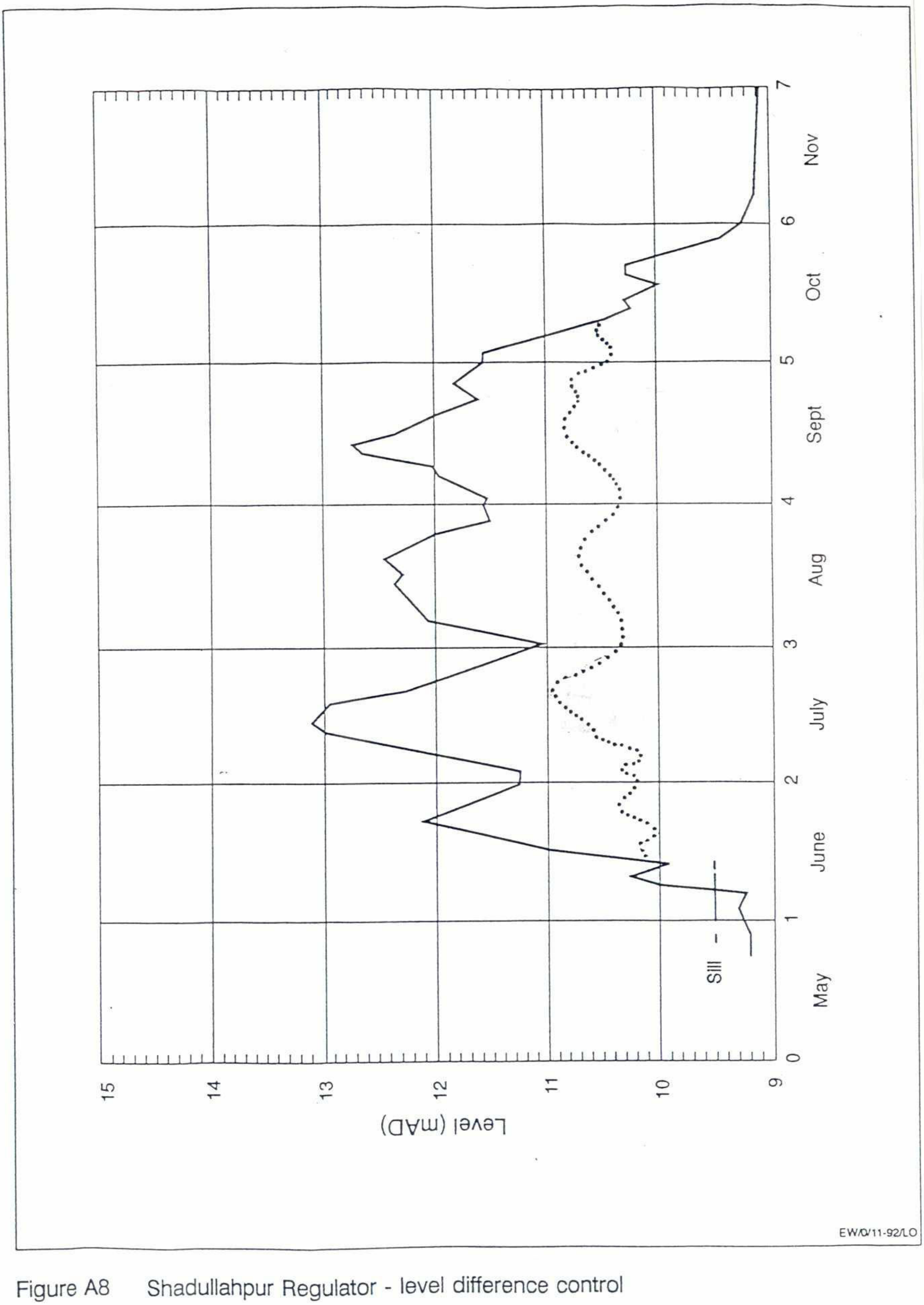

Figure A8 Shadullahpur Regulator - level difference control

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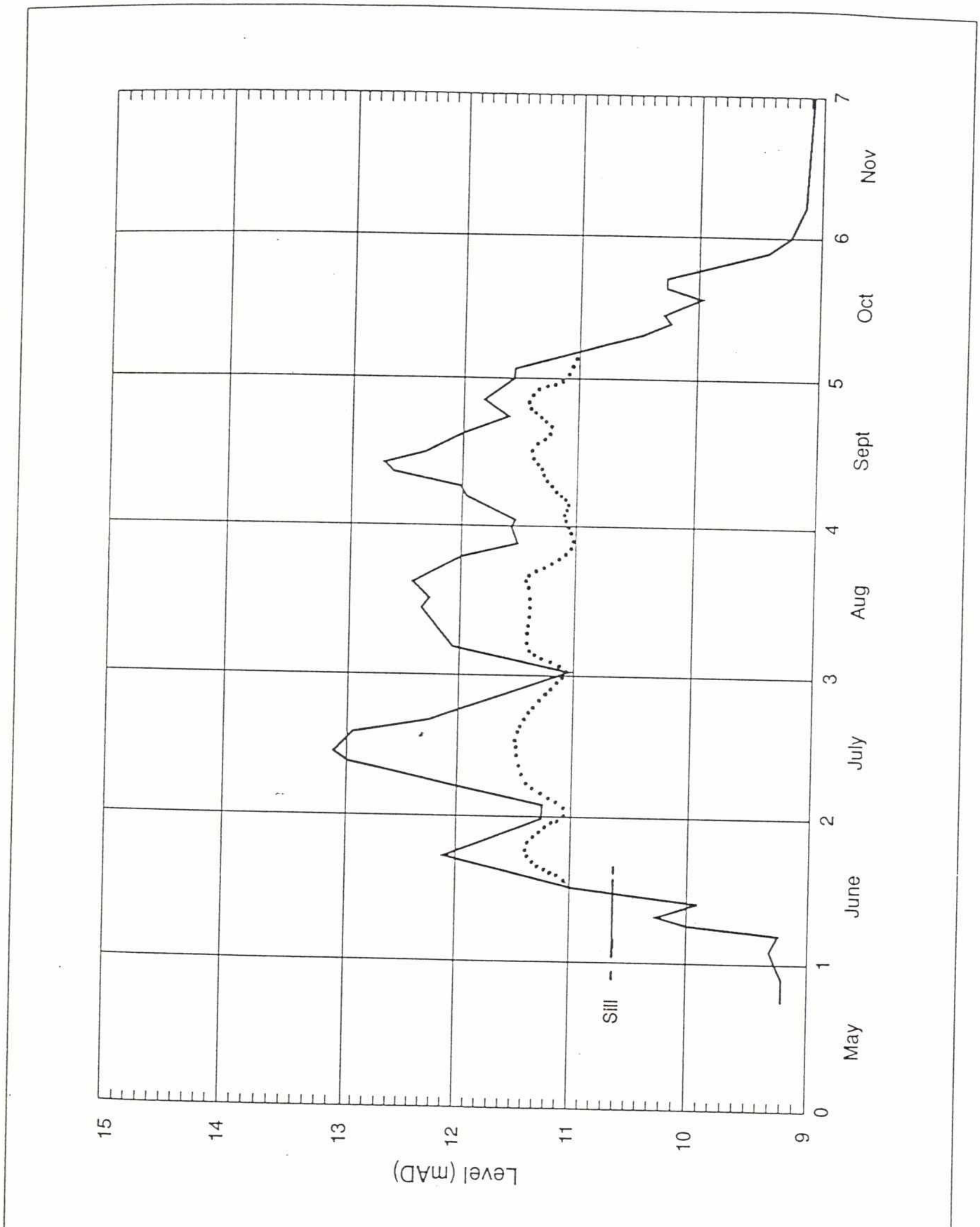

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Figure A9 Jugini Regulator - level difference control

Appendix V:

Structures to assist fish migration through major obstructions such as dams and weirs.

Appendix V

Structures to assist fish migration through major obstructions such as dams and weirs.

General Principles

There are basically two types of fish pass: 1. the fish actively swim upstream, aided by the device and 2. the fish enter a strong compartment and are transferred over the obstacle without the expenditure of energy. The first class includes the "pool and weir" and "pool and orifice" type of fish passes, whilst the second involve the moving structures of the "fish lift" and "fish lock" type.

A major characteristic of a fish pass is the height at which it is optionally effective. The basic intention of a fish pass is to allow the fish to circumvent a barrier, usually where water levels are of a different height. **Pool** and **weir** type passes are most effective to a height of less than 10m whilst the **pool** and **orifice** variant may be used to negotiate heights of up to 40m. (Pavlov 1989). The more elaborate **fish lock** can be effective up to 40m whilst mechanical fish lifts which store and transport fish vertically, can be used to any height. In general, the greater the height tot be circumvented the more costly the device. Those mechanisms which physically aid the fishes tend also to be more expensive. In terms of the FAP, structures to be circumvented are relatively low, compared to hydroelectric dams for example, and differences in water height are likely to be quite small. Ideally, however, there should be a difference in water height since a flow of water is required to attract the migratory fishes.

The **principle objectives** (McLeod and Nemenyi 1940)

- Control water velocity below the swimming capacity of the fish
- Avoid rapid change in flow pattern
- Provide resting areas as required
- Operate without manual control
- Discharge enough water to attract the fish
- Pass a well-located fish entrance
- Be economical to construct and to maintain
- Operate without the interference of sediment and debris
- Require no more water than is available or can be allocated

The selection of any fish pass structures for the FAP should be consistent with these criteria.

Small Structures

Pool and Weir Fish Passes

Sometimes referred to as the "pool and traverse" pass (Beach 1984), this is the basis of the simplest fish ladder, in which a downward sloping channel is cut into a sequence of pools by a series of traverses or weirs (Fig 1). Each weir has a notch through which the migrating fish can swim in order to reach the next pool.

Recommendations on design requirements have been provided by Beach (1984) as part of UK regulatory requirements. These include:

- a the change in water level across a traverse must not exceed 0.45m
- b pools should have a minimum dimension of 3m long x 2m wide x 1.2m deep
- c traverses should be 0.3m thick with notches 0.6m wide and at least 0.25m deep
- d the downstream edge of both the notch and the traverse should be curved so as to reduce turbulence and prevent the formation of a free-spurting jet
- e the pass entrance should be located easily by fish at all flows.

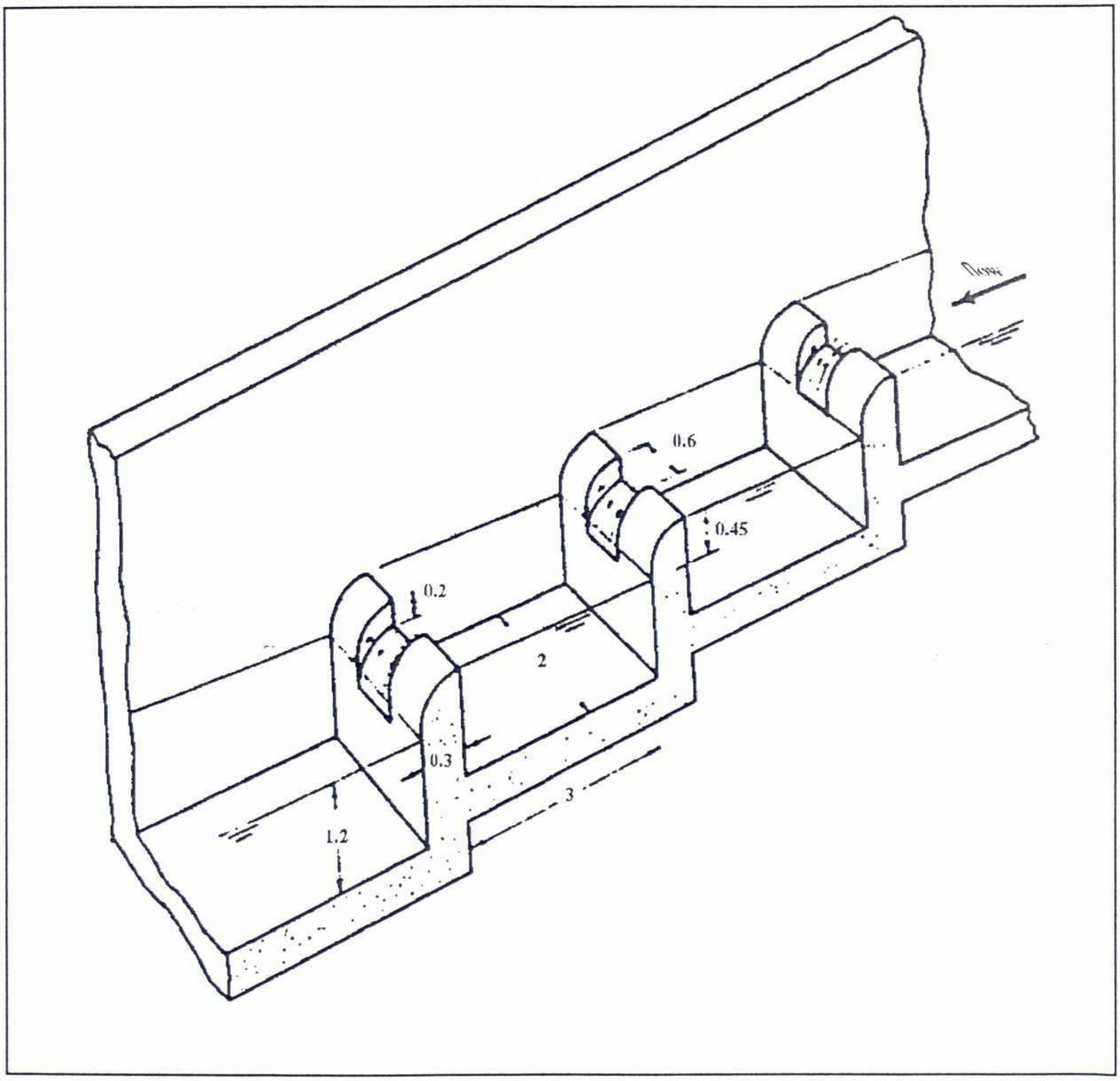

Figure 1 A schematic diagram of a "pool and weir" fish pass with notched traverses. The dimensions shown are recommended as the absolute minima. The head difference between pools should not exceed 0.45m. (After Beach 1984).

The position of the entrance to the pass is of particular importance since it must be readily located by fish under all flow conditions. if sited too close to a weir or other outflow, the turbulence from these sources may disorientate the fish a prevent them from detecting the pass outflow. The pass outflow should also be downstream of any other in the vicinity, particularly those of "non-passable" discharges, since these might otherwise preferentially attract the migrating fishes.

A particular advantage of the pool and weir type of fish pass is that it also facilitates the downstream migration of drift of young a juveniles. Fro this reason, the upper "exit" should be placed in a position with regard to the upstream flow where it can readily be located buy those young fish as well as by returning adults.

The pool and weir type of pass has been used extensively in Europe and North America although most commonly in connection with the passage of members of the salmonidae (salmon and trout), most of which are powerful swimmers. Quiros (1989) documents 29 fish passes which have been built as part of the impoundment of regulation of South American rivers. All but one of these are of the pool and weir type. The scale of many is rather larger than the dimensions given above, but those given by Beach (1984) can most properly be considered as the minimum dimension. The fish for which these South American fish passes have been built, however, have more in common with the Asian fish fauna of Bangladesh than the salmonid communities of the northern latitudes. They are used successfully by both the pelagic powerfully swimming characins, such as Prochilodus, which may roughly equate to the major carps, and also by the bottom-moving types such as the catfishes (Quiros 1989). The pool and weir type does, therefore, seem to work with communities of tropical and sub-tropical fish as well as for those of the temperate regions.

The pool and orifice pass is a variant on the pool and weir pass only in that passage between the two pools is through a hole in the weir wall rather than over a notch. This facilitates particularly the passage of bottom-moving species.

Denil Fish Pass

Similar to the pool and weir types, this relies upon the construction of a channel around or through the obstruction. In this case, however, the channel is traversed by a number of baffles which dissipate the energy of the current. The baffles are closely spaced and set at an angle to the axis of the channel. The notches in the baffles leave a relatively large portion of the channel available for the straight main flow through which the fish pass (Fig. 2). The shape and position of spacing of the baffles play an important part in the effectiveness of this type of fish pass. The hydraulics of passes of this type suggest however that the most economic design, with a readily located outflow and maximum space, is one with a gradient as steep as possible (Beach 1984). This pattern has been used successfully for salmonids in Canada, UK and Denmark. A detailed example has been given by Beach (1984) for a Denil Pass constructed on the tidal reaches of a river in UK. At low tide the difference in water level to be ascended was 2.25m whilst at high tide this was diminished and a proportion of the pass was submerged. This perhaps emulates the situation of a river in flood.

There are no records of the Denil Pass being used in the tropics and sub-tropics, but it may remain a possibility for by-passing the embankments of the FAP. Effectiveness does not seem to be restricted to salmonids since there are records of catfish of 11kg negotiating a Denil pass with a notch width in the baffles of only 2.25m (McLeod and Nemenyi 1940).

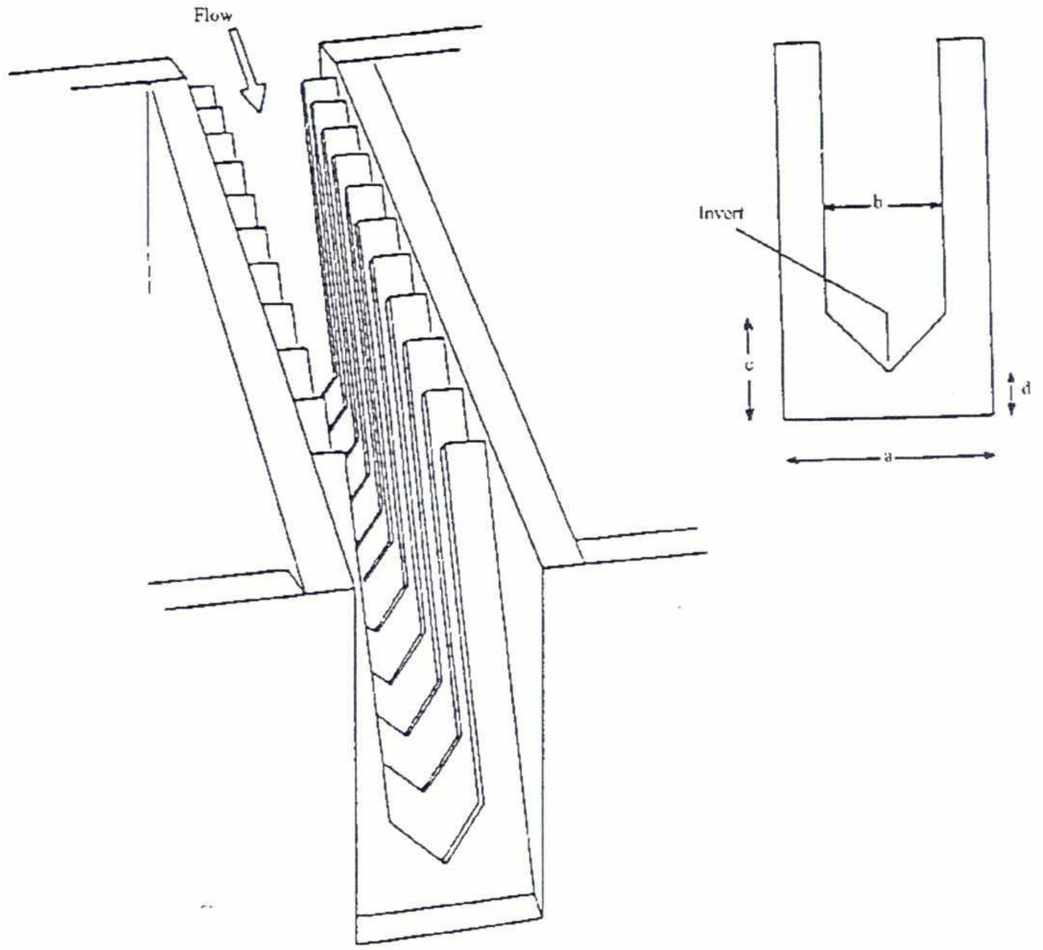

Figure 2 A schematic diagram of a Denil fish pass with single plane baffles. Inset is a diagram of a single baffle with the recommended proportions a:b:c:d: = 1:0.58:0.47:0.24; b is the fish free passage width, and the distance between consecutive baffles is 0.67 x a. (From Lonnebjerg, 1980 after Beach 1984).

Large Structures

Pool and Weir

The versatility of this type of fish pass does mean that it can be employed on a larger scale. Whilst a cheap, simple design may be used to circumvent a weir of 1-2m in height, they have been used to overcome major barriers. In South America, passes of this type have been used and have been constructed to heights of up to 20m (Quiros 1989). For the most part, however, passes of this height are associated with dam construction for hydroelectric schemes.

Fish Lifts

Fish lifts typically comprise of: a collection gallery; an operation chamber with a fish retention grid where fish may be counted and samples taken; and a moving and releasing device. They are associated mostly with dams in hydroelectric schemes and, in order to attract the fish, use the plume of water from both the turbines and the collection gallery. The migrating fishes swim up the plume and into the collection gallery which may be over 150m long. Periodically, the inlet is closed by a crowding device which prevents the fish drifting back into the tailwater pond. The crowding device is then moved towards the dam, which shepherds the fish int ot operation chamber of the lift itself from where they are raised to the outlet chute at the upper level of the dam (Fig. 3). Such devices can be mechanically or hydraulically driven.

Fish lifts can be very effective when correctly sited and operated. The Volgogradsky hydraulic lift on the Volga River allows more than one million fish of all types to pass upstream each year (Pavlov 1989). Fish are attracted into the collection gallery by water velocities of 0.8 - 1.8m sec^{-1}.

Sluice Fish Passes

There are variants of the fish lift design. They are operated, rather like locks, by the raising and lowering sluice gates alternately at the entrance and outlet parts (Fig. 4). During the collecting period, the sluice gate controlling the entrance to the collecting chamber is raised. This is closed periodically and the fish are concentrated at the distal end of the pass by the crowding screen, by which time the water level in the operation chamber has filled to the level of the reservoir. The upper outlet gates can then be raise to allow the fish to move out into the reservoir. Again, these have been used for a wide variety of fish in the former Soviet Union (Pavlov 1989).

Fish Locks

The most commonly used pattern of fish lock is the Borland type (Clay 1961). This consists of a lower entrance chamber and an upper exit chamber, connected by a inclined shaft (Fig. 5). The fish are attracted into the collection chamber by the flow allowed down the inclined shaft from the upper water level. The lower sluice gates can then be closed to allow the inclined shaft to fill with water level. The velocity of the flow coming down the channel and out through the entrance is governed by the aperture of the upper sluices.

A substantial example of this type of fish pass was build against the Salto Grande dam on the middle reaches of the Uruguay River (Quiros 1989). It proved successful for the passage of both pelagic and bottom-dwelling species, however, it was noted that the pelagic species often shoaled outside the device, in which there was no light, inhibited their entry initially. it was noticed also that many fish did not enter, probably owing to the extensive areas of turbulence near the entrance of the pass. It was in fact felt that a greater degree of planning expensive. The two Borland locks at Salto Grande cost around US$1.2 million. The flow velocities for attracting the fish in this device ranged from 0.1 to 1.8m sec^{-1}.

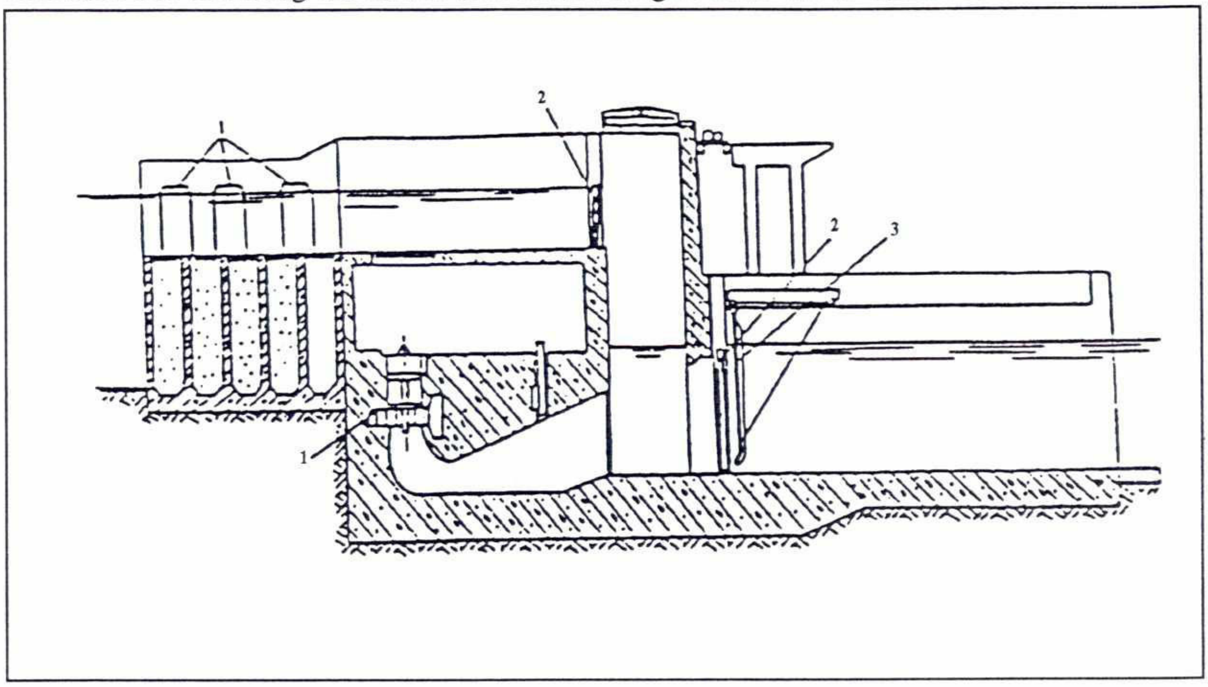

Figure 3 The fish lock of the Volzhskaya hydroelectric dam on the Volga River. 1. outlet orifices, 2. operational gates, 3. crowding device, 4. hydroelectric unit (after Pavlov 1989)

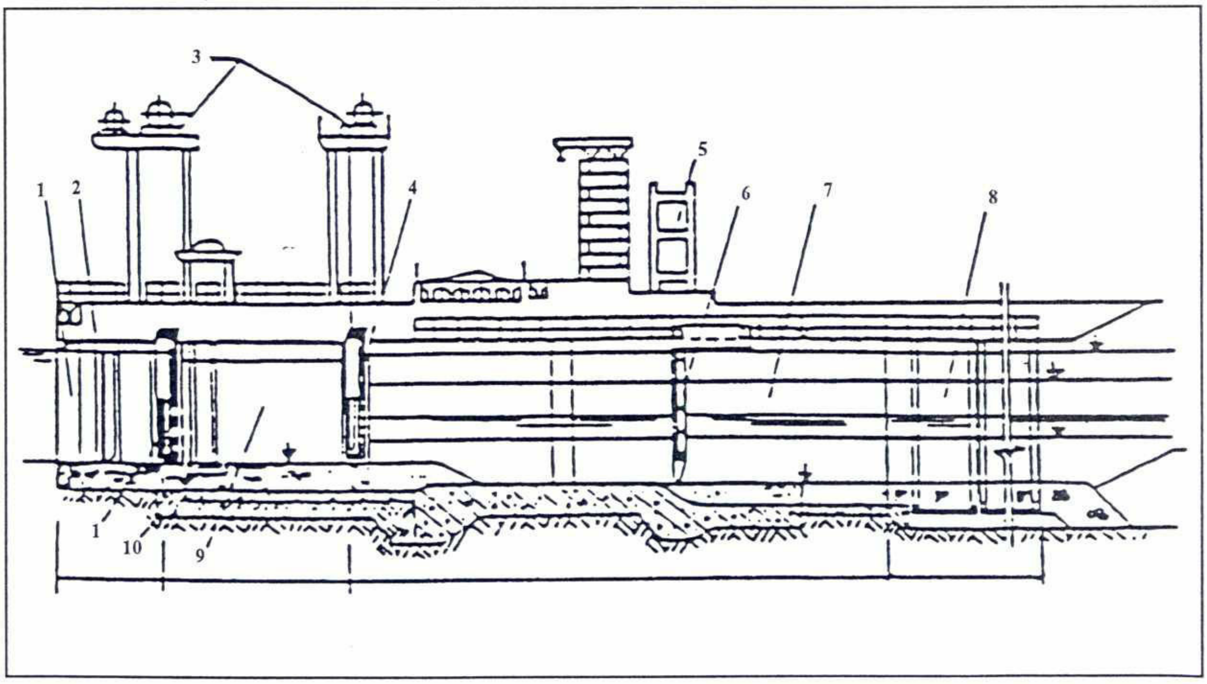

Figure 4 Longitudinal section through the sluice fish-pass at the Fedorovskiy hydraulic scheme on the Kuban River. 1. outlet chute, 2. litter-retaining screen, 3. gate control mechanism, 4. gates. 5. control structure, 6. crowding screen, 7. fish-collection gallery, 8. low approach chute, 9. working chamber, 10. fish-retention grid (after Pavlov 1989).

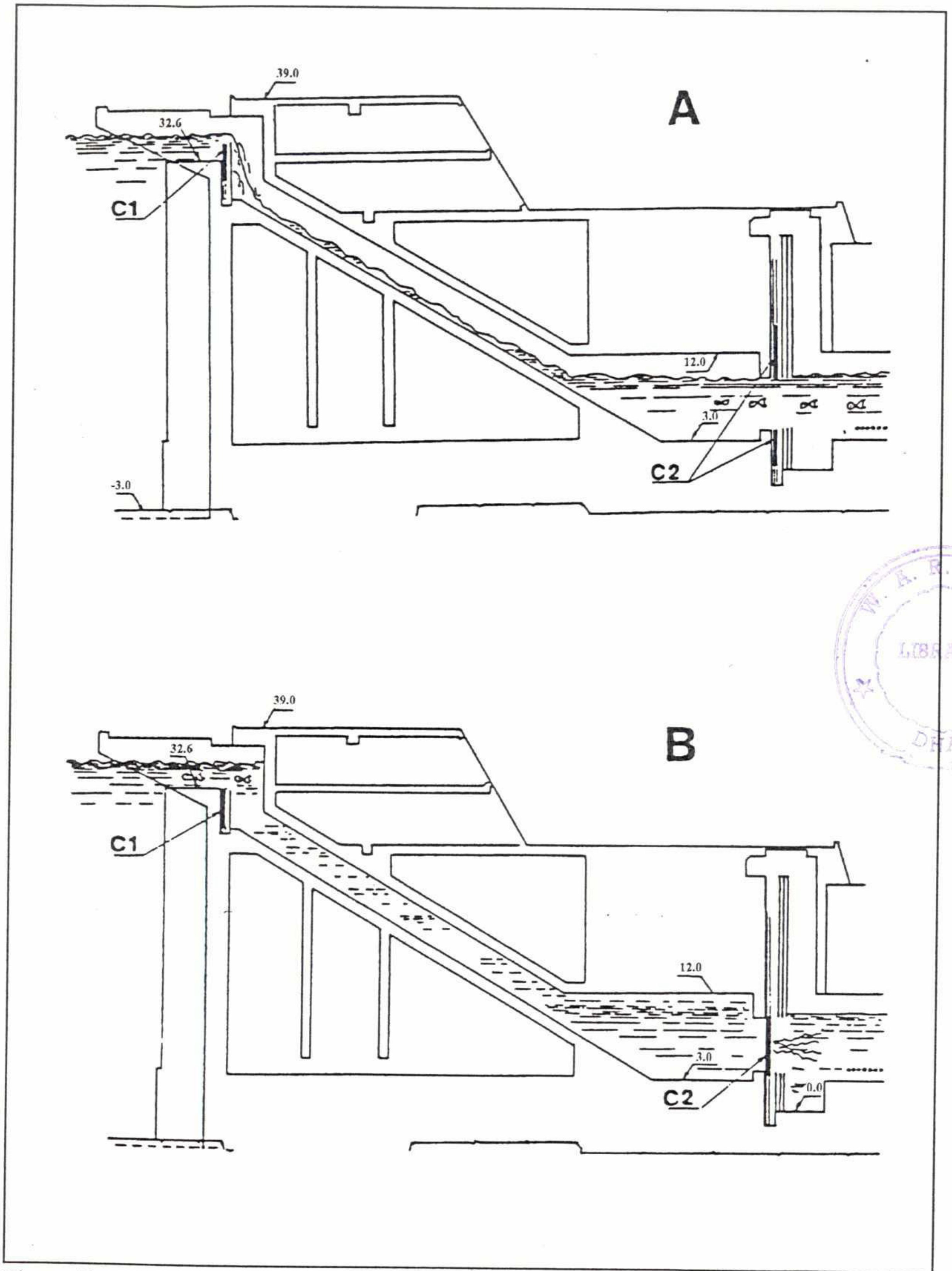

Figure 5 Borland lock operation
A. Fish entering the lock
B. Fish leaving the lock
C1. Upper sluice-gate
C2. Lower sluice-gate
(after Quiros 1989)

Appendix VI:

References

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Appendix VI:

References

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