# IMPORTANCE OF DAM OPERATION FOR DOWNSTREAM RIVER HEALTH

**VIVEK P. KAPADIA**
*Water Resources Department, Government of Gujarat, Gandhinagar, India*

## ABSTRACT

*India is considered a water stressed country since water availability in many states have been below the threshold value i.e. 1000 $m^3$ per capita per annum. From independence onwards, focus on storage of water has been always witnessed in the financial planning at the levels of the State Governments and the Central Government. India has increased its storage capacity after independence from 15 Billion Cubic Meter to 200 Billion Cubic Meter by constructing more than 4000 dams which is not a small accomplishment. It has paid a lot to the country in the form of food security and economic strength. But at the same time the ecological issues in all the river basins have been becoming more and more critical with the passage of time and even the downstream flows (with respect to the dams) are also diminishing with time which has posed a serious threat against the very life of the river. This phenomenon has brought the environmentalists and the engineers to the loggerhead. The main ideological war is between the advocates who are fighting for quenching the thirst of the human beings and the pleaders of protecting lives of the rivers which have been, since time immemorial, quenching the thirst of myriad of forms of existence including human beings. The former lot argues that the storage is more important than the flowing of the river and the latter underlines the critical importance of the flowing rivers. A sensible view that drives home the point that the dams are not meant to break the rivers but to modulate the floods and storing a portion of the monsoon waters that could be used in the non-monsoon period for productive purposes is lacking somehow. This means that the dam operation is required to be made in such a way that the downstream hydraulics, hydrology and ecology are least affected and a balance between the storage and the flowing nature of the river is duly attained. Some dams are demolished in European countries and the U.S.A. which were detrimental to the river ecology but India can at least think on the dam operation issue in a sensible and constructive manner to ensure a sustainable development without much harming the downstream health of the rivers. The paper focusses on the importance of the downstream health of the rivers and the measures especially in the form of dam operation that could ensure serving the said objective.*

## 1. EFFECT OF DAM AND HYDRAULIC SYSTEM, WATER CHEMISTRY AND ECO SYSTEM: AN OVERVIEW

A part of precipitation infiltrates in to the soil out of which some is percolated to the groundwater storage and balance is the interflow which flows through the soil to the river or drain. The part of precipitation that does not infiltrate in to the soil flows on the surface of the soil which is called run-off which also goes to river or drain.

"Rivers and groundwater are intimately connected across multiple scales. River water infiltrates into the surrounding bed and banks, travels along short groundwater flow paths, and returns to the channel. These flow paths define the hyporheic zone, a critical ecological transition area between fluvial and groundwater ecosystems, which mediates the exchange of water, nutrients, contaminants, and heat." (Stanford, 1988) "Rivers can receive groundwater contributions or lose water to the surrounding aquifer, and these large-scale flow patterns impact the finer patterns of hyporheic exchange. For example, groundwater discharge to a gaining reach limits the size of the hyporheic zone (Cardenas, 2007)". "Since reaches alternate between gaining and losing conditions over seasons and flood events (Krause, 2007)", "hyporheic exchange also varies (Wondzell, 1996)". Some reaches alternate between gaining and losing conditions daily in response to stage fluctuations. The penetration distance of river water into the surrounding aquifer prior to flow-path reversal determines the size of the hyporheic zone. The frequency of flow-path oscillations determines hyporheic residence times. "The hyporheic zone functions as a reservoir for solutes and energy in rivers and facilitates important biogeochemical reactions. Hyporheic exchange therefore affects water quality at the watershed scale (Harvey, 1998)." Some aquafers nearby the river channel are connected to the river channel have a tendency to receive some water from the river channel, hold it and then to release in the river when gravity permits. All such water contributions to the river channel which are transient in nature and form i.e. surface water and ground water at different locations and instances are generally known as baseflow once they appear in the river channel to be the part of the river flow.

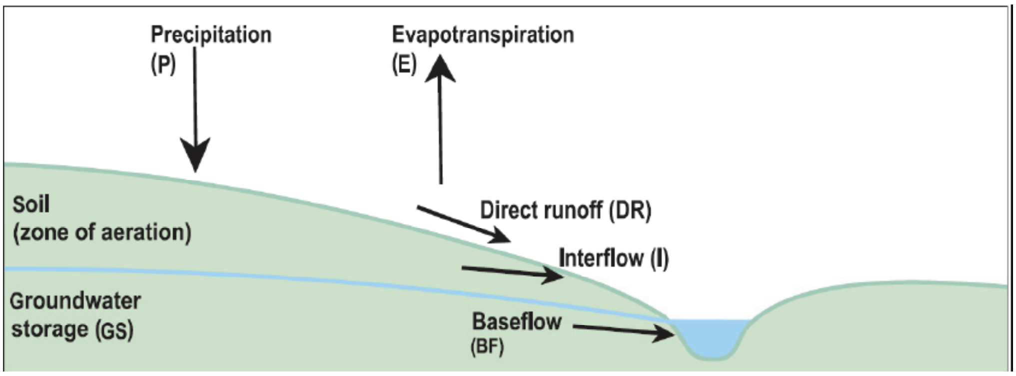


**Figure 1** : River Flow Ingredients

Hyporheic phenomena in case of dam are different from otherwise. "The residence times (hours) and path lengths (centimetres to metres) of dam induced hyporheic exchange are similar to hyporheic exchange induced by natural processes."[6] However, a fundamental difference exists between them. Dam-induced hyporheic exchange is intrinsically transient because unsteady pressures at the sediment–water interface drive the exchange. In contrast, 'natural' hyporheic exchange (due, for example, to flow over an undulating riverbed) is comparatively steady because time-averaged pressure gradients at the sediment–water interface drive the exchange.

Conceptual model of a natural river-groundwater system in a reach dominated by baseflow indicates how groundwater flows steadily through the riparian aquifer in one direction like water through a gill, during most of the year. Groundwater discharge to the river limits the size of the hyporheic zone. Conceptual model of a river-groundwater system downstream of a dam indicates how river water flows in and out of the riparian aquifer like air flowing in and out of lungs due to frequent stage fluctuations. The hyporheic zone includes all flow paths that start and end in the channel.

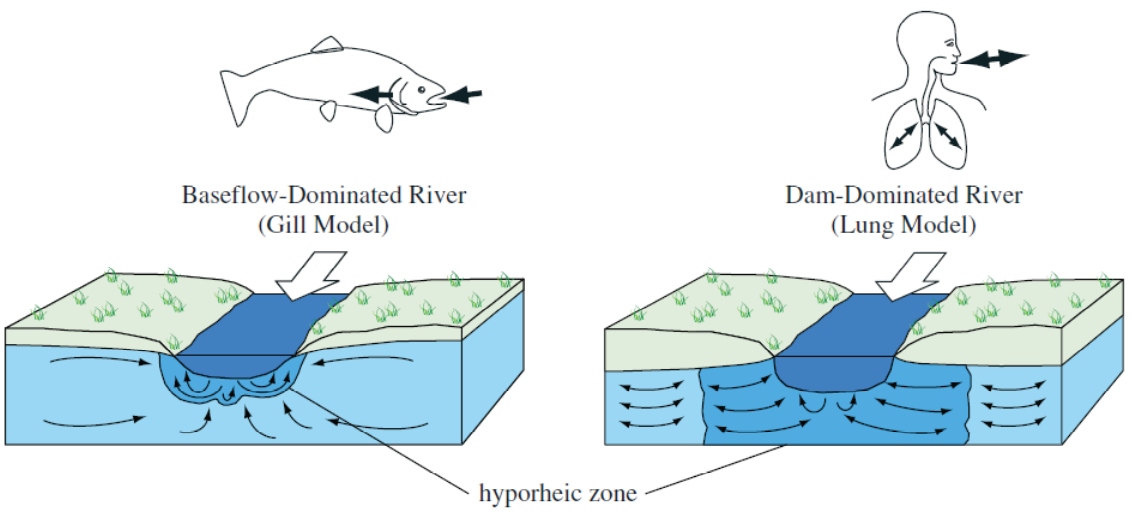


**Figure 2** : Conceptual Models of Baseflow-dominated River and Dam-dominated River (Audrey, 2009)

Dam operations fundamentally change the hydrological, thermal, and geochemical dynamics of riparian aquifers and their hyporheic zones. "In the absence of dam operations, groundwater would flow steadily towards the river through the riparian aquifer like water flowing through gills. The steady discharge of groundwater would limit lateral hyporheic exchange. In contrast, dam operations induce stage fluctuations that drive river water in and out of the riparian aquifer. The unsteady, reversing flow of water through the riparian aquifer is like the flow of air through lungs (Audrey, 2009)".

The result of dam on the downstream stretch of the river is gradual decline in the baseflow and over a period of some years the baseflow evanesces and the river dries up. Several perennial rivers of India have dried up after getting broken by dams.

Water chemistry fluctuates in both the river and hyporheic zone. The specific conductivity of river water is greatest in between dam releases during baseflow periods and lowest during dam releases when reservoir water dominates the flow. Hyporheic exchange transports the specific conductivity signal into the riparian aquifer. As a result, the specific conductivity of pore water near the channel is damped and lagged relative to the specific conductivity of the river. In the absence of dam operations, river and riparian aquifer chemistry would fluctuate less. The specific conductivity of river water would consistently resemble values measured during baseflow periods. Since steady groundwater discharge to the river would limit lateral hyporheic exchange, the specific conductivity of pore water near the channel would consistently resemble the specific conductivity of groundwater. Along steady groundwater flow paths, a ladder of redox conditions would also regulate nitrogen, sulfur, and organic carbon inputs to the river.

**Table 1** : Difference between baseflow-dominated river and dam-dominated river (Audrey, 2009)

| Variable | The Gill model: Baseflow-dominated rivers | The Lung model: Dam-dominated rivers |
|---|---|---|
| Water-table variation | Moderate to small | Rapid, large fluctuations |
| Hydrologic link to river | Steady groundwater flow towards river | Flow directions regularly reverse over short timescales |
| | Flood events can temporarily perturb flow paths and rates | |
| Hyporheic zone characteristics | Laterally limited by groundwater discharge to the river | Laterally extensive |
| | Flows driven by bedform topography, river morphology, and in-stream structures | Flows driven by river stage fluctuations downstream of dams |
| | Flows are generally steady but may vary in response to floods, seasons, and morphodynamics | Flow are unsteady and reverse at timescales of hours to days |
| Effects on river temperature | Hyporheic and groundwater inputs steadily influence river temperatures | Hyporheic and groundwater inputs only influence river temperatures when flow direction is towards river |
| Effects on river chemistry | Riparian aquifer is a sink for $NO_3$ and $SO_4$ and a source for DOC | Uncertain but likely a function of competition between hyporheic residence times and reaction kinetics |
| Effects on riparian aquifer chemistry | Variation in redox conditions with distance along groundwater flow paths | Uncertain but likely variable in both time and space |

Because of the dam operations, huge changes occur in hyporheic zone characteristics and river and aquifer chemistry, and, therefore, biological life of the river changes fast both in the reservoir and in the downstream. The parts of the biosystem that are affected from the dam are the watered parts on the shore. During the filling works of the dam, while the lands remain under water the land part of the region decreases. However, the water-land boundary extends. Thus, plant, animal or human being settlement areas change. Forests, agricultural areas may come under water. As the water level differentiates periodically, some species begin to live under water from time to time, in the tide zone. This area may turn to marshy land or reed bed depending on the soil structure. Water-soil-nutrient relations, which were settled after floods in the downstream of the dam, change in a long period of time. Furthermore, compulsory changes occur in flora, fauna and the agricultural traditions of people in the region. This effect can extend for Kilometers.

The existence of the dam becomes a threat for the fish species spending certain parts of their life in the spring or in the flood water and other parts in the cross section where the river joins sea. Some sea fishes come to fresh water and swim up to the spring in order to lay eggs. Later on, they return to sea with new young fishes. A dam that will be built on this way will interrupt the life cycle of these creatures and cause deaths in a mass. By-pass flows are designed for this purpose in some rivers as a mitigating measure to allow bilateral passage for such fishes.

## 2. DEVELOPMENT OF HOLISTIC PERCEPTION FOR WATER AND ECOLOGY

Construction of dams remained a major activity for several years to meet the ever increasing demand of the human civilization. Severe flow regulations and diversion of surface water had no consideration for the health of the downstream stretches of the rivers and livelihood concerns of the riparian people for a long as the ill-effects were not known to the planners and engineers. In Europe and U.S.A., severe effects on biodiversity came to the notice in the mid of the twentieth century and the concept of the environmental flow emerged.

In 1990 the Global Consultation on Safe Water and Sanitation for 1990s was held at Delhi, India it was emphasised on protection of the environment and safeguarding of health through the integrated management of water resources and liquid and solid waste. Integrated Water Resource Management conventionally addresses the conservation, utilization, management, etc. but this event emphasised the environment as a perspective of the Integrated Water Resource Management which was a very important dimension of viewing the water management.

In 1992, International Conference on Water and Environment was held at Dublin which concluded that fresh water is finite and vulnerable resource, essential to sustain life, development and the environment. Thus, life, development and environment were viewed holistically.

In 1992, United Nations Conference on Environment and Development was held at Rio de Janeiro from where which an important guiding principle emerged that protection of water resources, water quality and aquatic ecosystems should be essential objective of water resource management.

In March, 2000 the Second World Forum and Ministerial Conference was held in Hague where The World Water Vision was presented with three primary objectives: (1) to empower people and communities to decide how to use water, (2) to get more crops and jobs per drop and (3) to manage use to conserve fresh water and terrestrial ecosystems. This was a major thrust on preservation of ecosystems amongst growing demand of fresh water for the needs of human beings.

In August, 2013, at the Stockholm World Water Week the most important achievement of all deliberation was cultivation of sense that the environment should no longer be seen as “separate” from human spheres. India also passed through the same phase with some delayed sequence of events.

In all the deliberations on water resource management, there had been the central idea of conservation of river ecology. During last 25 years, the science of environmental flow has gained a large scale support and a significant development of methods of computing environmental flows for rivers has taken place as a result of several dialogues. This changed the water resource management strategies and emphasis on ecosystems and sustainable and perennial flows of rivers became a significant feature of the basin level planning.

In the post-independence era, i.e. after 1947, the main issue was of food security for which creation of storage potential was must and hence India constructed more than 4000 dams in only 40 years. Most of the Indian rivers have now been excessively exploited to fulfil ever-increasing demand from power, agricultural, industrial and municipal sectors. Now the ill-health of the downstream stretches of the rivers and ecosystems have been acknowledged in India and hence some mitigating measures are being taken up. Main thrust is in the form environmental flow like Europe and USA. However, river restoration has been a more popular term in India which includes environmental flow, pollution control, baseflow revival, etc. Environmental flow is being studied for many rivers like Ganga, Yamuna, Satluj, Godavari, Narmada, Tapi, etc. but the implementation needs more serious efforts.

## 3. EXPERIMENT WITH MAHI RIVER OF GUJARAT, INDIA

Mahi is a river in western India. It originates from Vindhyachal Hills, Madhya Pradesh and after flowing through Rajasthan, enters Gujarat and meets in Bay of Khambhat. Its total length is 583 Km. and catchment area is 34842 Sq. Km. Bhadar is right bank tributary and Panam, Kun and Goma are left tributaries of Mahi River. A lot of people worship to Mahi River and lot more religious places and temples are situated by its shore. Due to the enormousness of the river, it is also known as a Mahisagar.

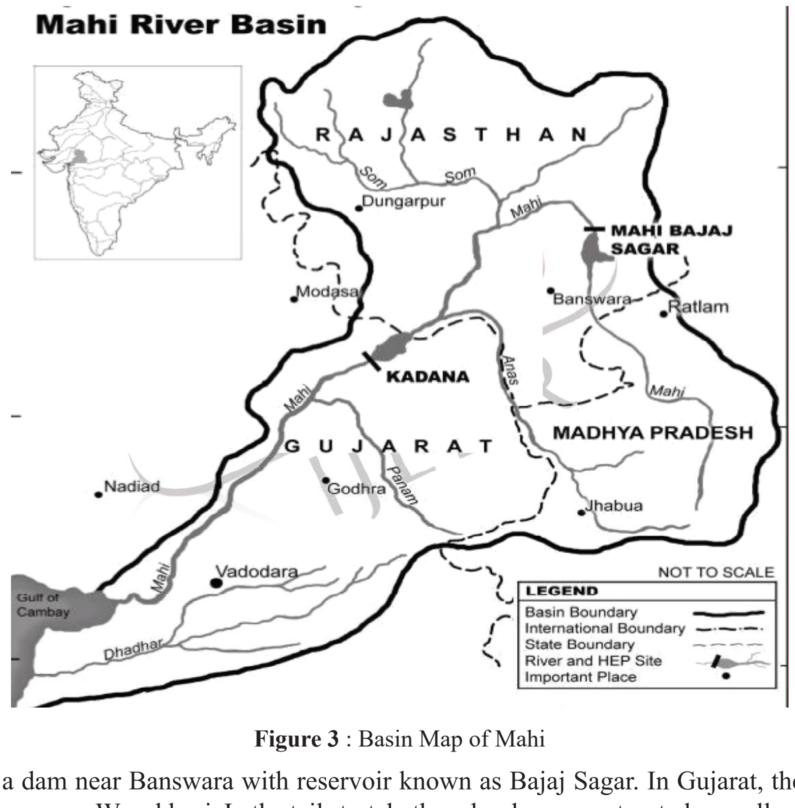


**Figure 3** : Basin Map of Mahi

In Rajasthan, there is a dam near Banswara with reservoir known as Bajaj Sagar. In Gujarat, there is a dam known as Kadana and is a weir known as Wanakbori. In the tail stretch, there has been constructed a small weir known as Sindhrot. Length of river from Wanakbori weir to the ocean is 120 Km approximately and from Sindhrot weir to the ocean is 35 Km. Thus, the flow is highly regulated.

Mahi estuaries has been facing serious issues of salinity ingress and rising saline levels in groundwater. According to CAG Report 2011, Salinity ingress area has been increased by 15 %. Compared with the data of 1977-1984, there has been an addition of 88,947 hectares to the affected areas. According to the Central Pollution Control Board, Government of India, the major reasons for polluted Mahi river stretch in Gujarat are effluents directly discharged by the factories into the water bodies and domestic effluents released by the municipalities. Millions of litres of untreated or semi-treated effluents are dumped in the river.

The downstream zone of River Mahisagar is known for diversity of fish fauna during post monsoon season. This zone has both fresh water and estuarine regime and hence, fishes of different ecosystems are represented in the survey. Total 26 species were reported from 03 orders and 12 families having diverse food habits and ecosystem as listed in Table 2. However, the diminishing number of fishes became a concern for all in last two decades.

The primary reason for diminishing number of fishes was restricted release of flow from the dams. From 2006 to 2013, average release per day during post-winter i.e. January to June was only 0.24 Million Cubic Meter (MCM) in the tail stretch of Mahi river. Post-winter flow has the maximum effect in the estuarine zone of a controlled river as immediately after the monsoon, there is base flow and hence the effect of the release from the dam is not exclusive. Continuous deterioration of water quality up to 2104 was alarming and that justified sensible intervention. In 2014, the flow in river remained very high as an exceptional case due to heavy rainfall in the entire basin and dams in the upstream stretch were full and huge hydropower was also generated. But then were systematic and sincere efforts to release some water in to the river in spite of shortage of water in the upstream dams by generating hydropower such that the average daily non-monsoon flow remains 0.75 MCM. It was aimed at improving the subsurface water quality and health of the river in the tail stretch. Hydropower generation was not the primary objective.

**Table 2** : Fish Faunal Diversity of Downstream Zone of Mahi River (Gohil, 2013)

| **Sr. No.** | **CLASS: PISCES** | | **SUB-CLASS: TELEOSTEI** |
|---|---|---|---|
| | **Order** | **Family** | **Genus and species** |
| 1 | Acanthoptergii | Percidae | Ambassis ranga |
| 2 | | | Therapon jarbua |
| 3 | | Gobiidae | Gobius giuris |
| 4 | | | Boleophthalmus glaucus |
| 5 | | Rhynchobdellidae | Mastacembelus pancalus |
| 6 | | | Mastacembelus armatus |
| 7 | | Mugilidae | Mugil belank |
| 8 | | | Mugil corsula |
| 9 | | Ophiocephalidae (channadae) | Ophiocephalus marulius |
| 10 | | | Ophiocephalus punctatus |
| 11 | | Cichlidae | Oreochromis mossambicus |
| 12 | Ancanthini | Pleuronectidae | Cynoglossus macrolepidotus |
| 13 | Physostomi | Siluridae | Macrones seenghala |
| 14 | | | *Arius nenga* |
| 15 | | Scombresocidae | *Belone annulata* |
| 16 | | Cyprinidae | Labeo boggut |
| 17 | | | *Labeo rohita* |
| 18 | | | *Cirrhina reba* |
| 19 | | | Cirrhina fulungee |
| 20 | | | *Barbus sarana* |
| 21 | | | Barbus ticto (Puntis ticto) |
| 22 | | | *Rohtee cotio* |
| 23 | | | Chela bacaila |
| 24 | | Notopteridae | Notopterus kapirat |
| 25 | | Clupeidae | Engraulis mystax |
| 26 | | | Clupea fimbriata |

Consistent efforts of maintaining enhanced flow in the tail stretch of Mahi river yielded some encouraging results in the form of water quality of the aquifers. Important determinant of the health of the river is the fisheries production. Some water quality parameters have also been studied and the health of the river could be assessed based on the results. Impacts on both the aspects – water quality and fisheries production have been studied and discussed in a nut shell.

An important fact is that the fishermen community had never flourished in the surrounding of the Mahi river as the yield of fish used to decline fast and hence many of them preferred to change the source of livelihood, but whosoever remained in the same profession could not earn sufficient to invest further. In spite of all these limitations they witnessed a big change in the yield of the fishes after 2015. Average annual catch not only got doubled but rare species like Hilsa has been found in large numbers during last three years.

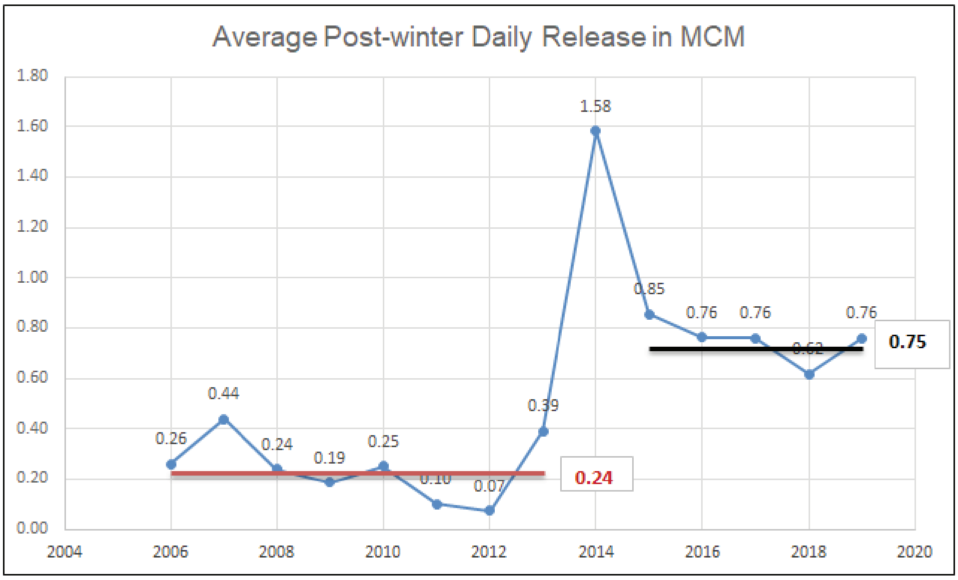


**Figure 4** : Average Post-winter Daily Release in Mahi River

**Table 3** : Annual Post-winter Daily Release and Fisheries Production

| Year | Average Post-winter Daily Release in MCM | Annual Estuarine Fisheries Production in MT (Metric Tonne) | Average Long Term Annual Estuarine Fisheries Production in MT (Metric Tonne) |
|---|---|---|---|
| 2006 | 0.26 | 394 | |
| 2007 | 0.44 | 444 | |
| 2008 | 0.24 | 2072 | |
| 2009 | 0.19 | 1686 | 1235 |
| 2010 | 0.25 | 1760 | |
| 2011 | 0.10 | 1061 | |
| 2012 | 0.07 | 1216 | |
| 2013 | 0.39 | 1342 | |
| 2014 | 1.58 | 2309 | |
| 2015 | 0.85 | 2246 | |
| 2016 | 0.76 | 2306 | 2270 |
| 2017 | 0.76 | 2211 | |
| 2018 | 0.62 | 2280 | |
| 2019 | 0.76 | 2360 (Provisional) | |

It is important to note that quantity of flow and yield of fishes can not be apparently correlated on a small time scale, but two distinct phases of relatively a long time scale with consistently low release and consistently higher release respectively clearly indicate the relationship between the two parameters. Behaviour of fishes is based on long term response of flow pattern and therefore is required to be evaluated with a long term database. The present experiment is going to become the basis for further scientific studies as they require some inputs in the form of results of some experiments without which they would merely remain a theoretical exercise. However, early results of the experiment are encouraging looking to the very objective and the scientific computations for the environmental flow followed by detailed research on ecosystem would certainly help in enhancing the river system as a whole in the coming years. Studies of fisheries along with improvement in water quality linked with release pattern would certainly project better defined principles which would improve the knowledgebase and reservoir operation techniques.

Water quality results on selective parameters obtained from water samples taken from an observation well in the downstream of the Wanakbori weir are shown in Table 4 in representative form such that post-winter variations could be better appreciated and correlated with the release of water. Continuous deterioration of water quality up to 2104 was alarming and that justified sensible intervention. Accordingly, the release from hydropower was decided and monsoon of 2014 gave a positive boost to the efforts. Water release of 2014 showed clearly that process of deterioration of water quality was effectively stopped and continuing more water release would bring positive changes in the water quality and hence was done so. The results were very encouraging and till date there has been a consistent improvement in the water quality followed by satisfactory maintenance of water quality in both the crucial stages of the water year - beginning of the post-winter phase i.e. January or pre-monsoon i.e. June.

**Table 4** : Water quality variations in post-winter phases

| Month and Year | TDS (Acceptable up to 450 ppm) | Conductivity (Acceptable up to 1000 µS/cm) | Magnesium hardness (Acceptable up to 110 ppm) | Total Hardness as CaCO3 (Acceptable up to 215 ppm) |
|---|---|---|---|---|
| Feb-13 | 629 | 1173 | 206 | 390 |
| May-13 | 748 | 1396 | 434 | 560 |
| Jan-14 | 1178 | 2198 | 818 | 1022 |
| Feb-15 | 1170 | 2182 | 492 | 700 |
| May-15 | 1190 | 2220 | 484 | 700 |
| Jan-16 | 150 | 280 | 84 | 130 |
| May-16 | 266 | 496 | 118 | 188 |
| Jan-17 | 254 | 473 | 80 | 154 |
| May-17 | 242 | 451 | 84 | 148 |
| Feb-18 | 265 | 494 | 86 | 150 |
| May-18 | 270 | 502 | 80 | 160 |
| Feb-19 | 280 | 523 | 100 | 166 |
| May-19 | 277 | 517 | 80 | 150 |

Coherence amongst the data of average post-winter release of water, estuarine fisheries production and water quality variations suggests that the endeavors made to improve the downstream river health have brought welcoming results.

## 4. FURTHER SCOPE AND CONCLUSION

Ecology of rivers with dams are susceptible to dangers if dam operations are not done sensibly and sensitively. Diminishing baseflow in the downstream of dam is the most serious threat for any river. With proper dam operations to ensure necessary release in the downstream, it becomes possible to enhance the ecology of the river and water quality of aquifers which are very essential for the overall health of the river. Health of tail stretch of Mahi river has come in to danger which got improved by persistent efforts in the form of enhanced release of flow.

Experimental data has now been sufficient to validate the mathematical models for computation of the ecological flow for the Mahi river in different stretches and that assignment could now be taken up. Unlike purely theoretical or *ad hoc* approach to computation of ecological flow, having validation data based on actual experiments *a priori* could certainly lead to a more rational approach to the ecological flow for any river. Ecological flow is not a static figure but varies for different phases of the water year and has direct relationship with the rainfall and dam operation and groundwater parameters and therefore, instead of depending on merely a theoretical exercise, a mixed approach should be resorted to in order to optimize the benefits of the release of water in the downstream of the dam and to ensure a proper balance between the objectives of conservation of water and of maintaining downstream river health.

The tail end structure on the Mahi river is Sindhrot weir whose actual objective is to fend the tidal influence. A fish-pass could also be designed provided on the side of the Sindhrot weir considering scientific data on aqua life and biotic characteristics of the same to allow migratory species to venture in the upstream stretches of the river. This could further improve the river health and river ecology. This provision is under consideration.

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