# Prescription for ecological flow provisions to sustain otter and fish habitat in the Pench river downstream of Totladoh (Upper Pench) Dam

Wildlife Conservation Trust

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**Citation:** Kelkar, N., Tumsare, V., Gaidhani, P., Nair, T., and Joshi, A. (2024). Prescription for ecological flow provisions to sustain otter and fish habitat in the Pench river downstream of Totladoh (Upper Pench) Dam. Technical Report. Wildlife Conservation Trust.

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**Image Credits:** Vivek Tumsare, Anooj Alukathra, Dheeraj Nagwanshi and Prasad Gaidhani

**Funding Support**

We are grateful to Astral Foundation, Wildlife Conservation Trust and Pench Tiger Reserve Maharashtra for supporting this work. We acknowledge the support of the Maharashtra Forest Department for providing necessary support to our field teams during the survey.

# ACKNOWLEDGEMENTS

We express our most sincere gratitude to Dr. Prabhunath Shukla (IFS), Field Director, Pench Tiger Reserve, Maharashtra for giving us this opportunity to carry out this study.

We thank the Astral Foundation for supporting this project.

We thank the Maharashtra Water Resources Department for sharing the valuable hydrological data.

We thank Shri D. S. Bharati, ACF (West Pench), and Smt P. S. Limbgaonkar, ACF (East Pench) for their valuable assistance.

We extend our heartfelt appreciation to -

Shri V. B. Rajurkar, RFO, East Pench Forest Range

Shri P. R. Lele, RFO, Nagalwadi Forest Range

Shri V. S. Chavan, RFO, West Pench Forest Range

Shri A. B. Ilamkar, RFO, Deolapar Forest Range

Shri J. R. Tayade, RFO, Paoni Forest Range

Shri S. B. Mohod, Saleghat Forest Range

Shri R. M. Shinde, Chorbahuli Forest Range

for their invaluable and timely support, along with the logical assistance.

We want to thank all the Round Officers, Forest Guards and Forest Watchers for their timely support and logistical assistance.

The dedication and cooperation of the field staff from diverse administrative units within the Pench Tiger Reserve were instrumental in facilitating the WCT field team with the necessary support, playing a crucial role in successfully completing the project's tasks. Their unwavering commitment and collaborative efforts are deeply acknowledged.

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## INTRODUCTION

In 2023, our team in the Conservation Research programme, Wildlife Conservation Trust in collaboration with the Maharashtra Forest Department, confirmed the presence of Eurasian Otters (*Lutra lutra*) in Pench Tiger Reserve (Gaidhani et al. 2023). This was the first confirmed record of the species from Maharashtra. Eurasian Otters prefer forested streams flowing through rocky and rugged terrain, where they feed on crabs and small fishes. The habitat preferences of Eurasian Otters differ from their counterparts – the more common and group-living Smooth-coated Otter (*Lutrogale perspicillata*), which prefers deeper water bodies such as reservoirs, tanks, and large rivers where they are able to get larger-sized fish prey. Eurasian Otter distribution is still not fully mapped in India, but from records since 2016, their occurrence across peninsular India appears to be largely restricted to forest streams within protected areas or higher-elevation forests. A notable exception to this observation includes the presence of Eurasian Otters in the Chilika lagoon of Odisha. Eurasian Otters depend on micro-habitats such as deep pools and in forest stream habitats. Flows of many such streams are regulated by the presence of dams. Seasonal dam operations that divert irrigation water into canals can directly impact stream flow and affect the distribution of fish and crab prey, thereby affecting Eurasian Otter presence and habitat use. The spawning and dispersal of many fish species, including endemic species, living in such streams are also directly affected (Palmer & Ruhi 2019, Li et al. 2019). Protected areas have been commonly designated around the catchment areas of dams and their storage reservoirs. Parts of the reservoir waters and the downstream river or stream stretches are often located within protected areas (Kelkar 2023), and surface water availability is also critical for terrestrial wildlife protection. In this regard, modifying the existing dam operations can lead to positive outcomes for the ecological water needs of both terrestrial and aquatic species even while managing present human water demands from the larger catchment area (Richter & Thomas 2007, Richter 2010, Bruno et al. 2022). These flows are called 'environmental flows' ', ecological flows', or simply 'e-flows', and are derived from a) hydrograph data and ecological knowledge on suitable conditions for the target species to survive and reproduce, (b) assessments of deviations caused by dam-modified flow conditions, and (c) the scope for modifying flow releases from dams, to maintain near-natural conditions in the habitats downstream (Acreman et al. 2014).

**STUDY AREA**

The Pench Tiger Reserve boundary in Madhya Pradesh and Maharashtra is contiguous with two large dam reservoirs: Upper Pench or Totladoh Dam and Lower Pench or Kamthikhairy Dam (Shende & Umare 2020). A four km stretch of the perennial Pench river immediately downstream of Totladoh Dam was identified as a habitat being used by Eurasian Otter during surveys in the winter of 2023-24. However, the probability of occurrence of Eurasian Otters in tributary streams and the 8 km stretch downstream of this habitat was estimated to be extremely low. Eurasian Otters are known to avoid deep backwater areas of reservoirs. In this stretch, the distance by river between the Upper Pench dam gates and the backwaters of the Lower Pench dam is around 12 km. Therefore, our goal was to estimate the 'ecological flow regime' or the seasonal and monthly flow requirements that would be needed to sustain fish and otter habitat in the entire 12 km stretch of the Pench River around the year, especially during the dry season months (November to May).

**Figure 1.** The target stretch for e-flow assessments with reference to Eurasian Otter and fish was identified as the 12 km stretch of the Pench river between the Upper Pench Reservoir and the backwaters of the Lower Pench Reservoir.

***Benchmarking and estimation of ecological flow requirements***

Our objectives were: 1) to assess hydrological attributes of the river stretch where Eurasian Otter presence was recorded for benchmarking, 2) to understand the nature of seasonal downstream flow allocations into Pench river from the Totladoh (upper Pench) dam, and 3) to analyse inflow-outflow data for Upper Pench Dam in order to estimate availability of ecological flow regime provisions into the Pench river, based on the benchmarks developed and the scope for optimization between irrigation and power demands, and ecological flow provisions.

## METHODS AND DATA

***Defining hydrological benchmarks for Eurasian Otter and fish habitat***

We analysed river channel width, depth, and morphology data for the 4-km stretch that had confirmed the presence of Eurasian Otters in December 2023. The presence of otters right below the dam gates was indicative of relatively better flow availability in the stretch closest to the dam, due to base-flows or minor spill flows provided by the dam. However, the flow in the stream was highly discontinuous, with water mostly retained in deep pool sections. Longitudinal connectivity was severed in most areas because of low flows being released from the Upper Pench Dam at that time. This may have had implications for the movement of fish prey to other areas and, in turn, explained the concentration of otter presence locations in the few pools that had water.

We found that in stream channels with otter presence, average channel depths were 1.3 ± standard deviation (SD) 1.13 m, with channel widths ranging from 10 to 90 m (average 30 ± 31 m SD). Disconnectivity and interrupted flows were the primary concerns underscoring the ecological flow requirements in the Pench river downstream.

**Figure 2.** A closer view of the Pench river downstream of Totladoh dam outlet showing the seepage accumulation in a deep pool right downstream of the dam. Otter presence was recorded here.


In streams without otter presence, depths were similar (average 1.54 ± 0.89 m SD) but channel widths were markedly smaller (average 22.86 ± 14 m SD). This indicated that the volumetric flow rate or discharge (expressed in cubic meters of water flowing through the stream per unit time) was lower in the sites further downstream along Pench river. Although there was one downstream section where water availability appeared similar to the channels with otter presence, otters were not recorded there.

Based on the above information, we set benchmarking criteria for ecological flows as follows: 1) river channels to have average depths of 1.5 m throughout the section, 2) channel widths wetted by water to be at least 30 m, and 3) flow velocity to be at least 1.0 m/s to ensure flow between disconnected pools from upstream to downstream. From the outflow data at the time of otter presence (December 2023), we set the minimum flow rate benchmark at 20 ± 5 $m^3/s$, which was the average observed daily discharge during a 10-day period when the otter survey was ongoing. The question then was to calculate the increment in flows needed to meet the ecological flow regime suitable for Eurasian Otters and fishes.

**Figure 3.** Sites of otter presence and depth and channel width measurements along the Pench river between the Totladoh and Kamthikhairy dams.

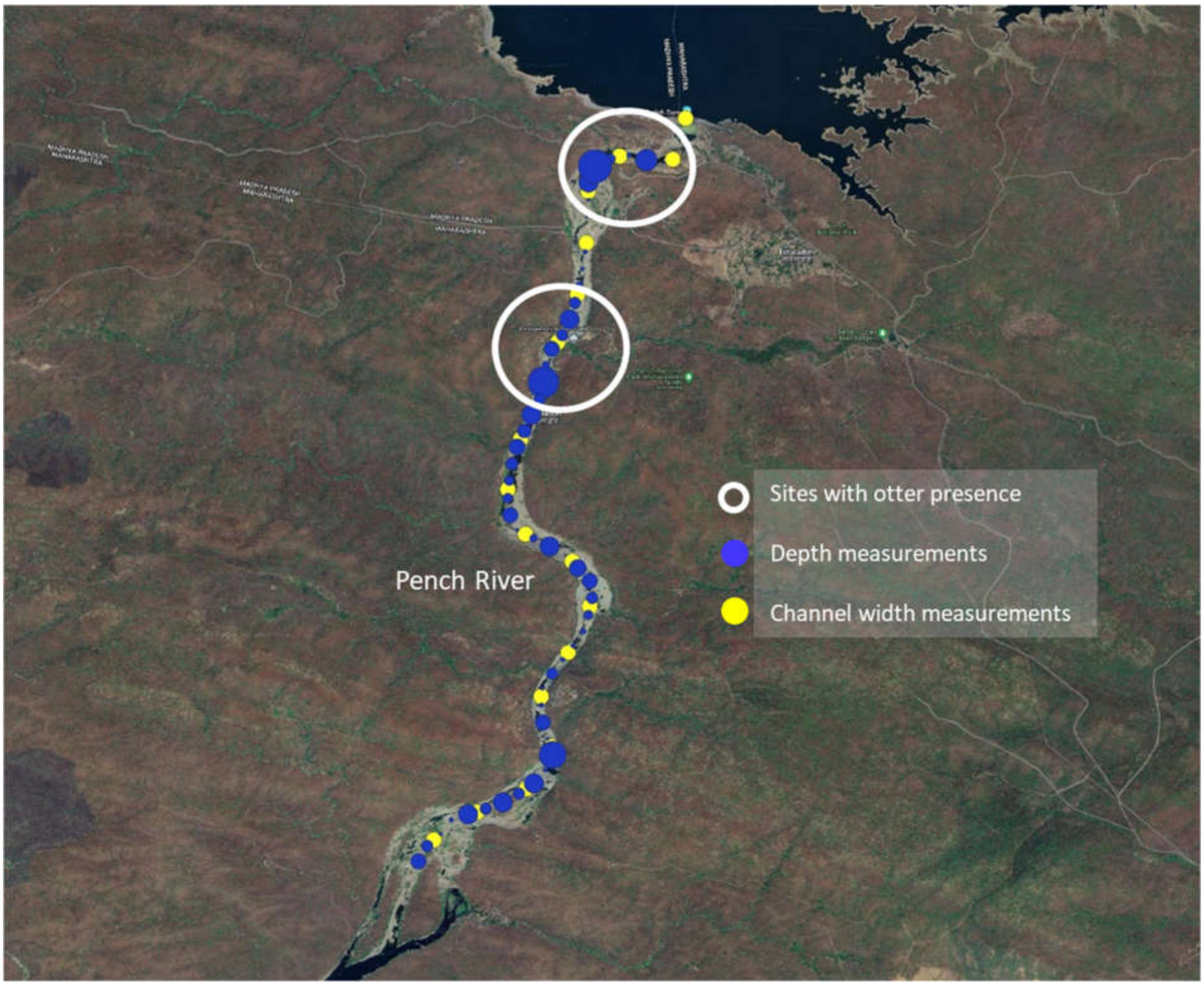
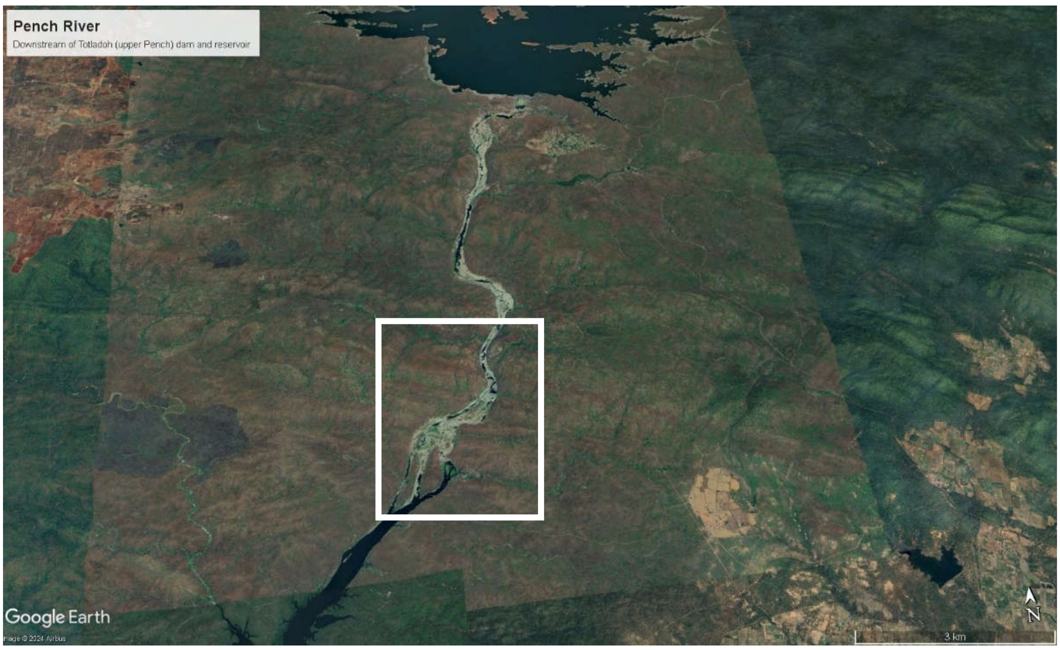



**Figure 4.** View of the lower pool habitat along the Pench river. Otters were not recorded here.



***Boundary conditions for optimizing ecological flow requirements***

The Upper Pench (Totladoh) dam and reservoir system receives water from the newly constructed (2019) dam at Chaurai in Chhindwara district, Madhya Pradesh. This project diverts Pench water upstream into the Kanhan, thus reducing the flows reaching Totladoh. Downstream, Totladoh dam needs to provide flows into the Kamthikhairy dam (Lower Pench dam) to maintain its storage and irrigation provisions. This flow provision into the Pench river is critical as it passes through the Pench Tiger Reserve (Maharashtra) and sustains the remnant otter habitat. In the dry-season (November to May), the outflow from Totladoh is a mere 1.5% to 7.5% of the total available water. About 2.1% of the outflow is due to seepage. A total of 30% annual flow is released downstream for environmental flow allocation (i.e. in the dry-season) from Totladoh between November and June, as per the current operating rule curve for the dam (GoMH-WRD 2017). This was verified to match for 2023-2024. Therefore, the important next step under ecological flow prescriptions is to redesign or modify seasonal or monthly outflows to prevent water flow availability shortfalls in the critical months from February to June, and in other months such as December. Our prescribed e-flow regime takes this into consideration. High levels of evaporation (up to 18%) have been a cause of concern for the Totladoh dam reservoir, as are high rates of siltation (0.785 mm/year), which are reported to be c.120% of the design-estimated siltation rates (0.375 mm/year). Siltation is a problem for many Indian dam reservoirs (CWC 2015), and the maintenance of water infrastructure is linked closely to the scope for e-flow provisions. For example, siltation may require dam gates to use ‘flushing flows’ of water, which can have negative ecological impacts on the downstream river channel. The daily reservoir storage and outflow data (in Million cubic meters) are presented in Figure 5, and rainfall (mm)-daily average flow ($m^3$/s) data are presented in Figure 6. Days are ordered as hydrological year days (June to May) as per the convention in water resource management data.

**Figure 5.** Data on daily total reservoir storage and outflow (downstream release) for Totladoh dam. Data received courtesy of Divisional Forest Office, Pench Tiger Reserve.

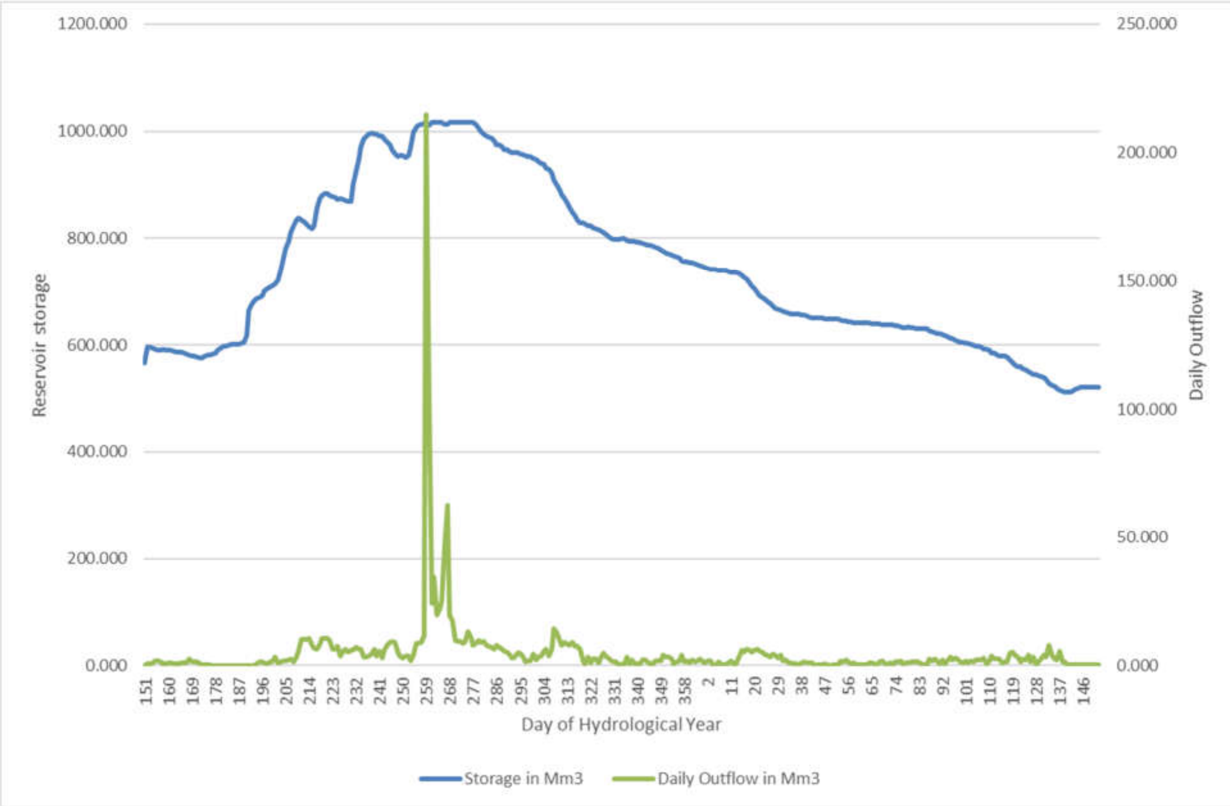
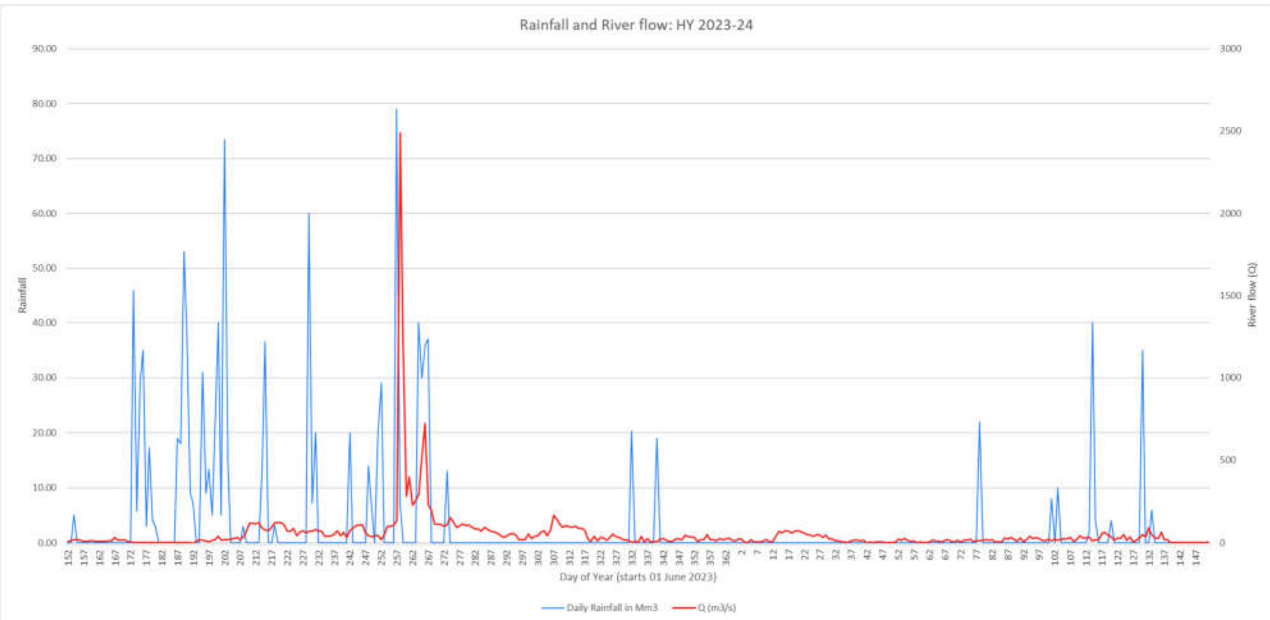



**Figure 6.** Daily rainfall (mm) and daily outflow into river ($m^3/s$) downstream of Totladoh dam. Note the high magnitude of flood-season release over 4-5 days in September, indicated by the sharp peaks.



***Dam water area and volume data***

Totladoh dam reservoir surface water area and volume, as estimated from Global Water Watch (Donchyts et al. 2022), showed a negative trend until 2019 following the construction of the Machagora (Chaurai) dam upstream in 2017 (Figures 7, 8). However, the diversion of 10 TMC-ft water from the Kanhan dam into Totladoh dam led to restoration of its storage (WAPCOS 2019).

**Figure 7.** Trends in surface water area (km$^2$) of Totladoh dam reservoir (1991-2024). Source: Global Water Watch.

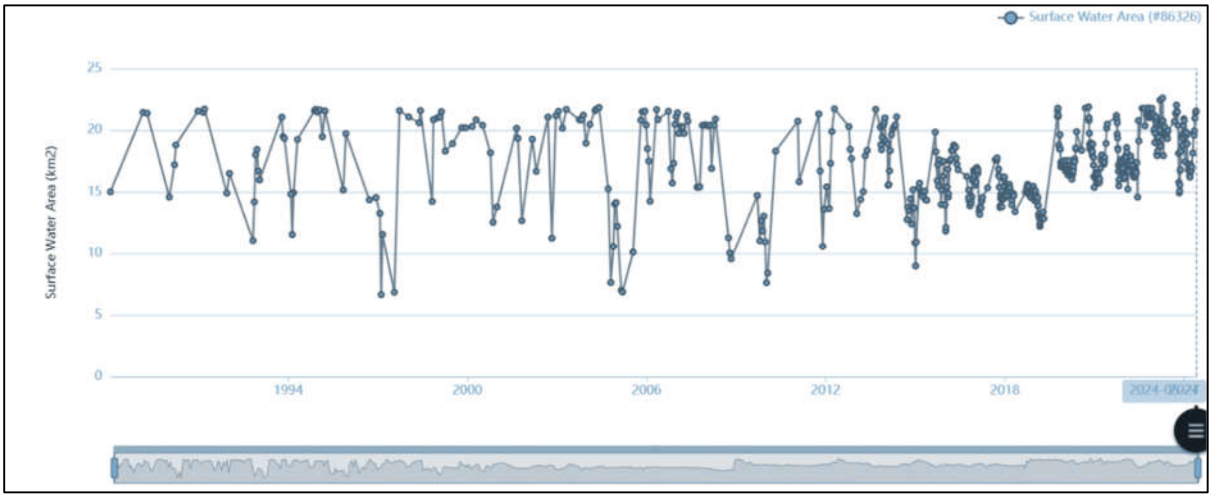
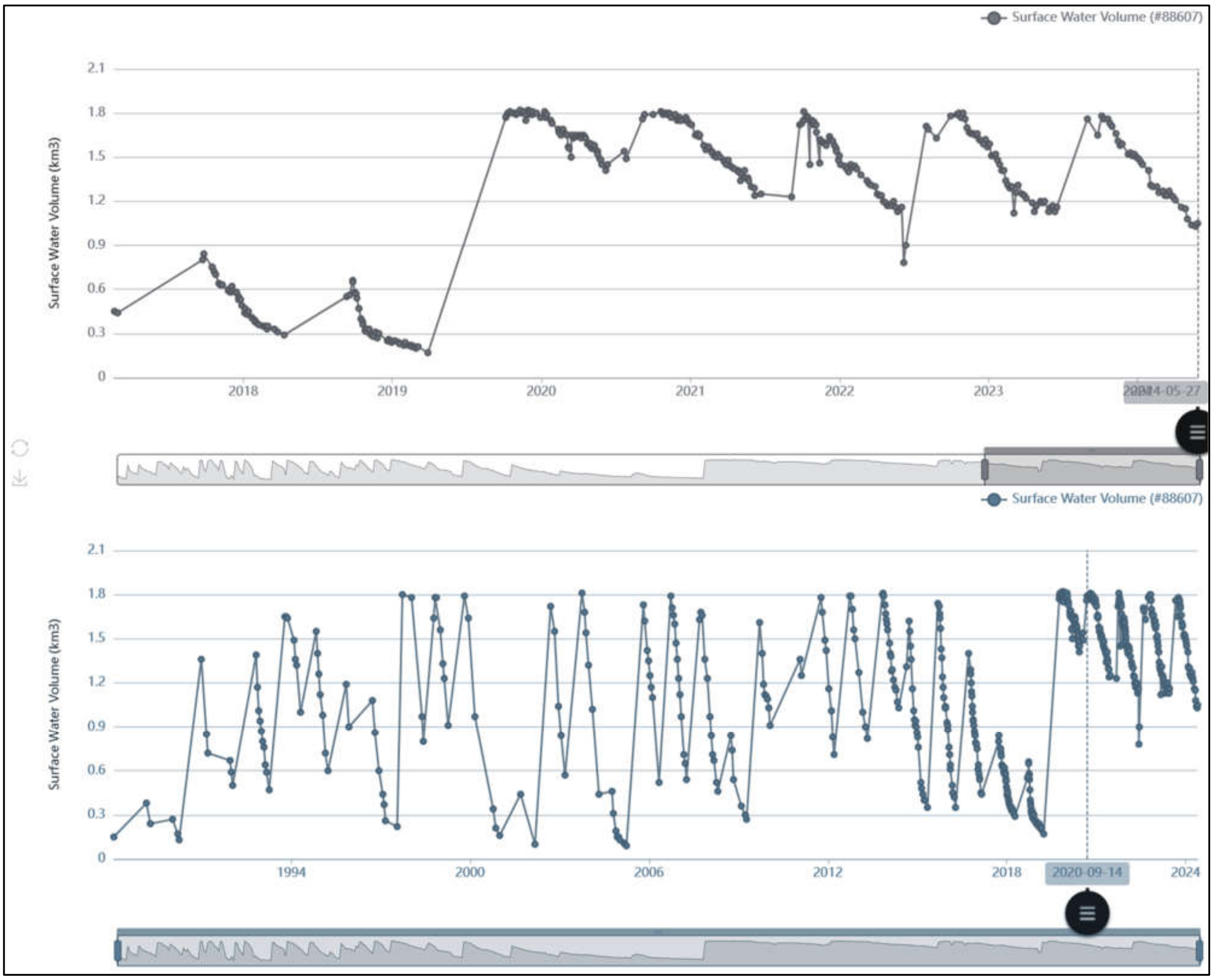
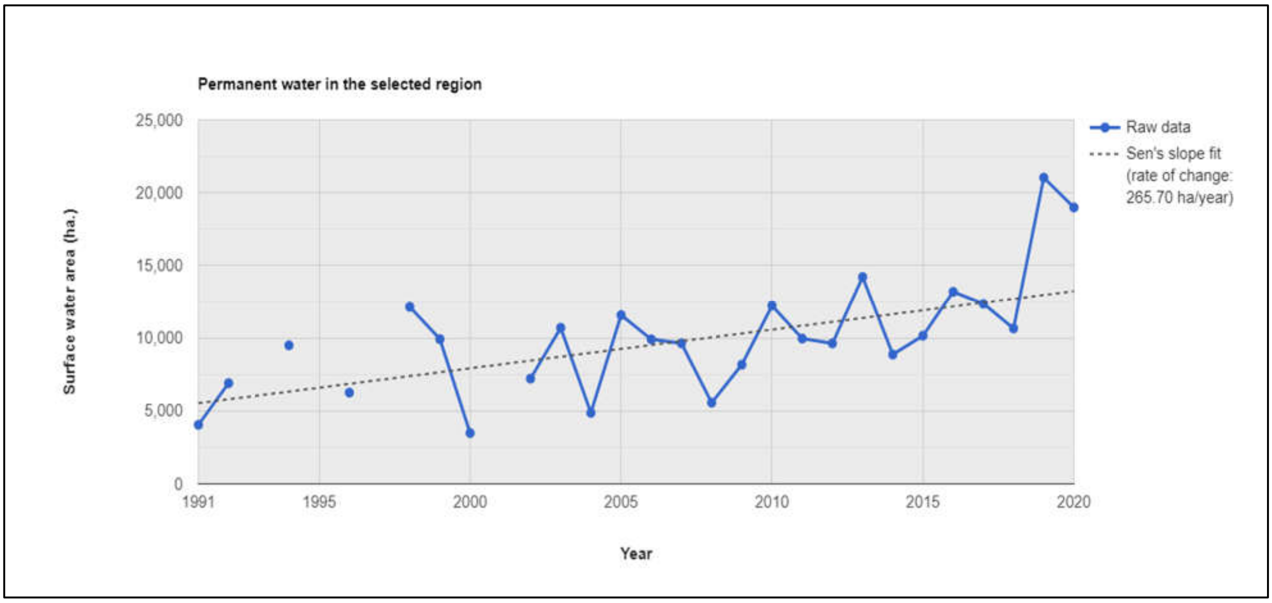


**Figure 8.** Trends in surface water volume (km$^3$) of Totladoh dam reservoir (1991-2024). Source: Global Water Watch.




An increase in permanent surface water area has also been identified by the Surface Water Trends-India dataset for the Pench river basin, with a monotonic increase at the rate of ~266 ha water per year (Figure 9). This increase could be due to new constructed storages and inter-basin water transfers.

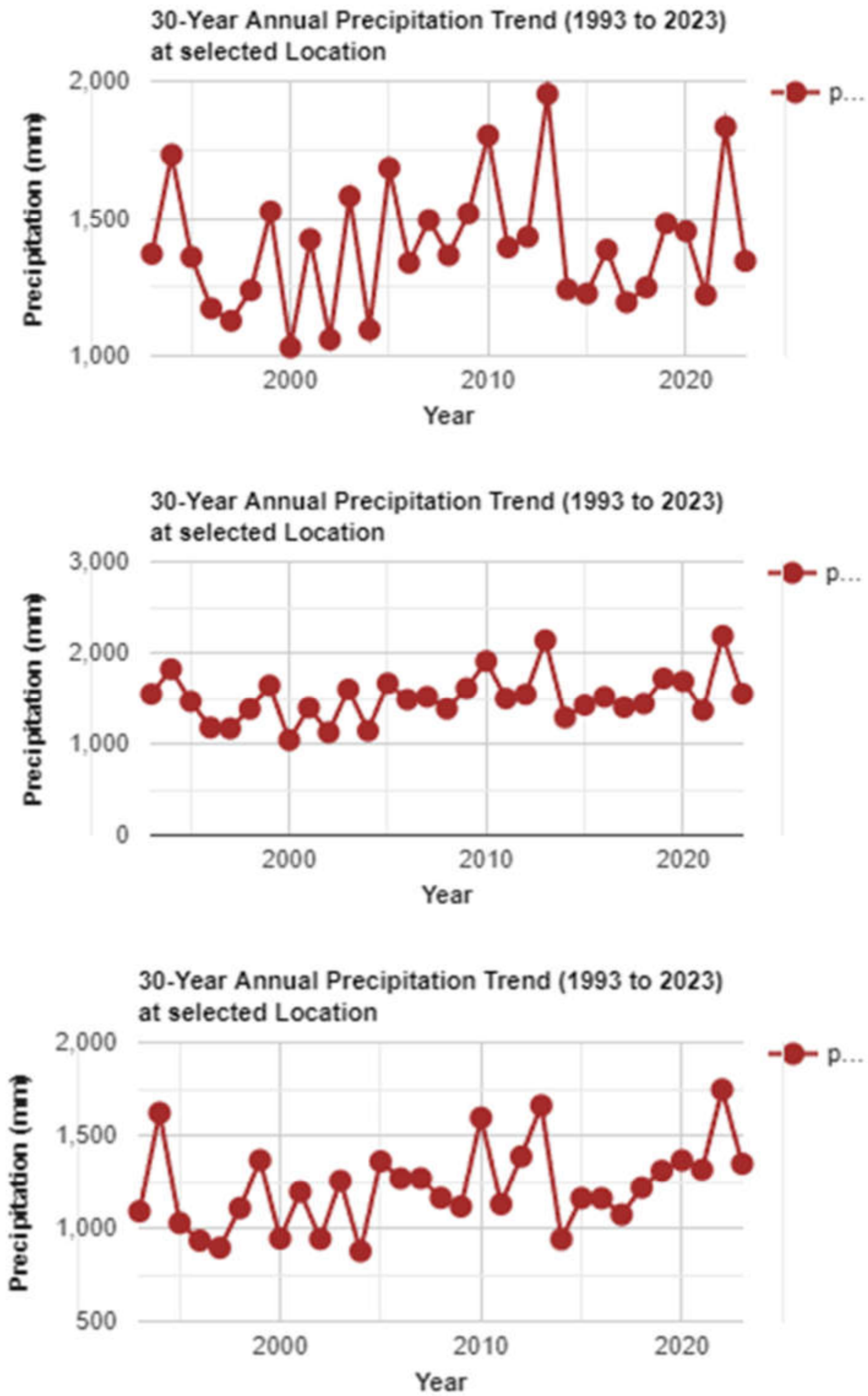
**Figure 9.** Permanent water area (ha) in the Pench river basin has shown a strong increasing trend until 2020. Source: Surface Water Trends-India (Koulgi & Jumani 2024). URL: https://sites.google.com/view/surface-water-trends-india/map?authuser=0




***Rainfall trends***

Upstream and at Pench reservoir, annual rainfall trends (1993-2023) did not show clear trends, and indicated stability despite some years with high rainfall variability. Downstream of the dam, rainfall did show a slight increase since 2015-16. Thus, the reservoir water inflow did not seem to be influenced by rainfall increases and was attributable to inter-basin water diversions upstream of Totladoh.

**Figure 10.** Trends in annual rainfall (mm) from 1993 to 2023 for sites upstream of Totladoh dam (top), at the reservoir (middle), and downstream in the Pench TR (bottom). Source: CHIRPS (https://chc.ucsb.edu/data/chirps).
URL: https://shikha-gupta.projects.earthengine.app/view/worldwide-precipitation-and-trend-analyzer



***Geomorphic Instream Flow Assessment Tool (GIFT): E-flow estimation from river channel hydraulic models***

The principle of the GIFT tool works on approximations of the Manning's Equation (see Gordon et al. 2004), which assumes that for bank-full conditions, the flow velocity is a function of the equilibrium between the gravitational and frictional forces. The GIFT tool has been used for ecological flow assessments in India as well, for species such as the Ganges river dolphin (Sonkar et al. 2022). From this, the discharge of the stream can be estimated without the need for direct measurement of cross-sectional flow velocity (which is not easy). The GIFT tool thus allows for extracting hydraulic relationships between water depth, flow velocity, channel width and discharge for ungauged river stations (McParland et al. 2016). The hydraulic simulation component of GIFT uses a reach-averaged channel cross section of bankfull geometry. Using the input data, an index of bankfull channel shape ($b$) is calculated that ranges from 0 (rectangular channel) to 1 (highly skewed channel). To simulate flow hydraulics below bankfull, the model iteratively reduces the water level until zero flow (Gronsdahl et al. 2017). For each modelled water level, mean velocity and depth is calculated. For this estimation, the tool needs inputs on sediment roughness (or grain size distribution; see Eaton et al. 2019) to represent frictional force opposing the gravitational flow, which is represented by the river bed slope or gradient (in m fall in elevation per m distance travelled downstream). These values need to be calculated in the field or with the use of remote sensing. For slope estimation, we used an Aster GTM Digital Elevation Model (GDEM). For the estimation of D84 ($84^{th}$ percentile of grain size distribution, in mm), we used the general theory on sediment sorting by rivers as discussed in Neely and DiBiase (2020). The data on bankfull width and depth was obtained from the global database developed by Andreadis et al. (2013). Details of the basic parameterization of the GIFT model are provided in Table 1. GIFT hydraulic models were run with these inputs and the flow thresholds were estimated for the following target conditions: Depth >= 1.3 m, Velocity <= 1.0 m/s, Width > 30 m.

**Table 1.** Parameter inputs to the GIFT model for an ungauged location downstream of the Totladoh dam on the Pench river inside Pench Tiger Reserve.

| GIFT model parameter | Input value | Source | Remarks |
|---|---|---|---|
| Mean bankfull width (m) | 144 | Andreadis et al. (2013) | Line shapefiles based on the HydroSHEDS dataset can be downloaded for all continents, here.[1]<br><br>The 5% value of bankfull depth would indicate dry-season conditions. |
| 5% bankfull width (m) | 46 | Andreadis et al. (2013) | |
| Maximum bankfull depth (m) | 6.9 | | |
| Mean bankfull depth (m) | 2.8 | Andreadis et al. (2013) | |
| 5% bankfull depth (m) | 1.17 | Andreadis et al. (2013) | |
| River bed slope (m/km) | 8 | ASTER GDEM V3 | ~30 m resolution within 1° tiles[2] |
| D84 (mm) | 600 | Neely & DiBiase 2020, Patil et al. 2023, Eaton et al. 2019 | Based on the exposed river sediment morphology and relative sizes of cobbles, gravel, and finer material |

[1] http://gaia.geosci.unc.edu/rivers/; [2] https://asterweb.jpl.nasa.gov/gdem.asp

### *Deficit and surplus flow calculations*

After the calculation of ecological flow required by otters in the dry-season, based on the reference conditions in sites where otters were detected in our survey, we calculated the deficit and surplus flows available in the downstream section: 1) daily, 2) ten-daily, and 3) monthly. These calculations were based on the stream flow estimated from the GIFT hydraulic modelling. We used four thresholds of stream flow from the model outputs: a) bare minimum, b) minimum flows, c) satisfactory (25 $m^3/s$), and 4) ideal ecological flows (35 $m^3/s$). For deficit calculation, the number of days per month, and the number of ten-daily periods with flows below these thresholds were calculated. The months critical for e-flow maintenance and modified dam release schedules were identified from this analysis. The average discharge per month was also assessed relative to the four thresholds to assess monthly deficits and surpluses. The reason to calculate the deficit at three different periods was to identify the relevant time-scales for ecological flow requirements to be met, with minimum disturbance and low short-term variability in stream flow (Wang et al. 2021). This ensured that the ecological flow regime was possible to design keeping the hydrograph qualitatively similar to the likely natural flow regime was maintained. The changes required to the present altered flow regime were also specified in the prescribed e-flow regime.

### *Development of ecological flow regime for Pench river downstream of Totladoh dam*

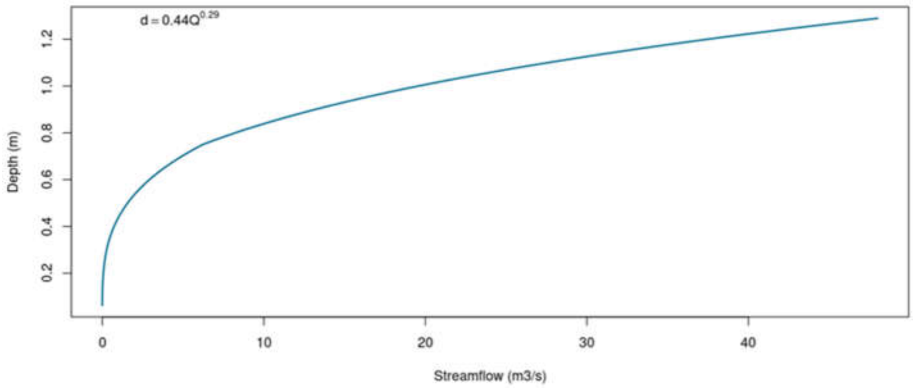
Based on the observed outflow data from Totladoh dam, and the background conditions, we identified monthly excesses and deficits, which could be used in a modified flow regime for the Pench river. The modified regime was based on maintaining the same volume of water released year-round and yet maintaining near-ideal flow conditions across months and seasons. For this, changes needed in some months' water release schedules were identified. Accordingly, a modified flow release curve was developed, which is the prescribed ecological flow regime. We focussed more on the summer dry-season months for the modifications because 1) water availability is most limited in this time, and 2) Eurasian otters most likely breed in this time, prior to the monsoon, making the availability of water and aquatic prey critical in this period.

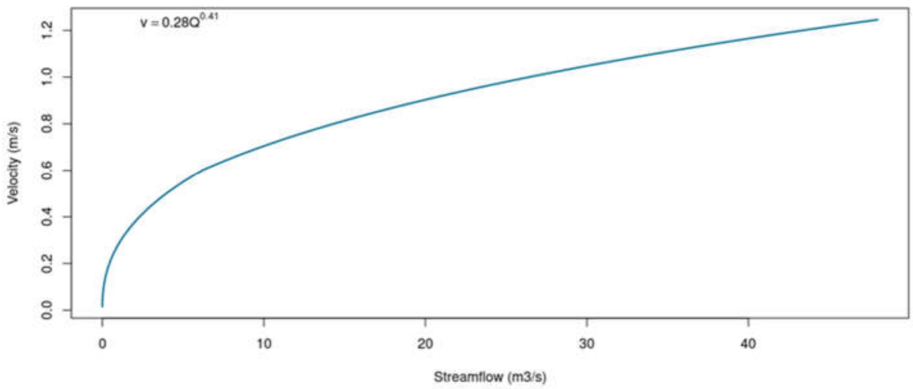
## RESULTS

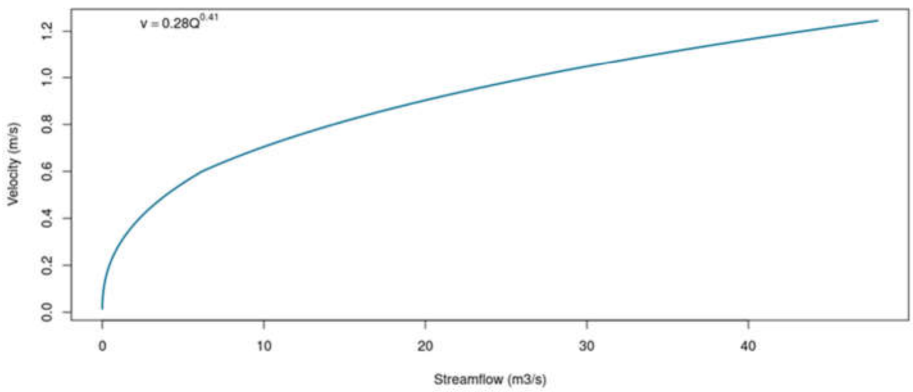
### *Estimated ecological flow thresholds in the GIFT model.*

Based on the GIFT models run, we derived three hydraulic equations in the form of power functions, as described in Figure X below. From these equations, the following e-flow thresholds were estimated: a) bare minimum (12 $m^3/s$), b) minimum flows (15 $m^3/s$), c) satisfactory (25 $m^3/s$), and 4) ideal ecological flows (35 $m^3/s$). These thresholds were named q12, q15, q25, and q35 respectively.

**Figure 11.** Hydraulic equations derived for Pench river below Totladoh dam, based on the Geomorphic Instream Flow (assessment) Tool (GIFT).



The non-linear relationship between stream flow and habitat conditions (depth, velocity, and width) described by the hydraulic equations shows that for small increments in streamflow released, a significant gain in the habitat conditions is possible to achieve. For example, with unit increase in streamflow from say 1 to 2 $m^3/s$, depth increments of 22% could be achieved. The graphs in Figure 11 show that decent habitat conditions in the Pench river inside the TR could be retrieved in a range of 25-35 m3/s in the dry-season.

***Deficit and surplus flow calculations***

We identified February, March, May, and June to be periods of deficit flows with respect to the four flow thresholds we identified in the 2023-24 hydrological year (June to May), with reference to the four thresholds. Days with deficit flows in Table 2 refer to lower flows than the thresholds. June, in particular, had the lowest observed flows, followed by February, March, and May, in that order.

**Table 2.** Number of days with lower flows than identified thresholds.

| **Month** | **Days with deficit (%) for q12** | **Days with deficit (%) for q15** | **Days with deficit (%) for q25** | **Days with deficit (%) for q35** |
|---|---|---|---|---|
| June | 20 (67) | 23 (77) | 29 (97) | 30 (100) |
| July | 14 (45) | 16 (52) | 24 (77) | 26 (84) |
| August | 0 (0) | 0 (0) | 0 (0) | 1 (3) |
| September | 0 (0) | 0 (0) | 1 (3) | 1 (3) |
| October | 0 (0) | 0 (0) | 3 (10) | 5 (16) |
| November | 4 (13) | 5 (17) | 9 (30) | 13 (43) |
| December | 8 (26) | 9 (29) | 22 (71) | 26 (84) |
| January | 8 (26) | 9 (29) | 14 (45) | 15 (48) |
| February | 16 (54) | 23 (79) | 28 (96) | 29 (100) |
| March | 14 (45) | 18 (58) | 29 (94) | 31 (100) |
| April | 4 (13) | 5 (17) | 16 (53) | 24 (80) |
| May | 14 (45) | 14 (45) | 19 (61) | 24 (77) |

**Figure 12.** Presence of deficit flows at ten-daily time-scales in the outflow provided to the Pench river in the hydrological year. These flows indicate critical time-periods for allocation of e-flow thresholds.

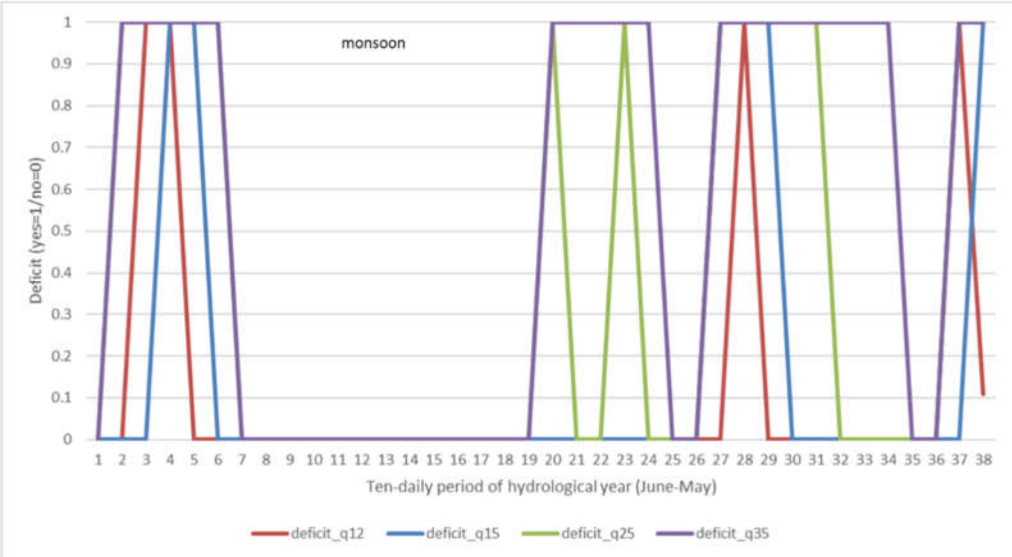



Figure 12 provides an intuitive graphic to understand how deficits in e-flows vary across the four thresholds for 10-day periods (n=37) through the hydrological year. Based on the target e-flows to be maintained, one can understand this graph as indicating a potential time-scale over which e-flows need to be maintained by improved downstream allocations.

**Figure 13.** Deficit and surplus flows in each of the dry-season months, including July at the start of the monsoon, for the four defined thresholds of flow.

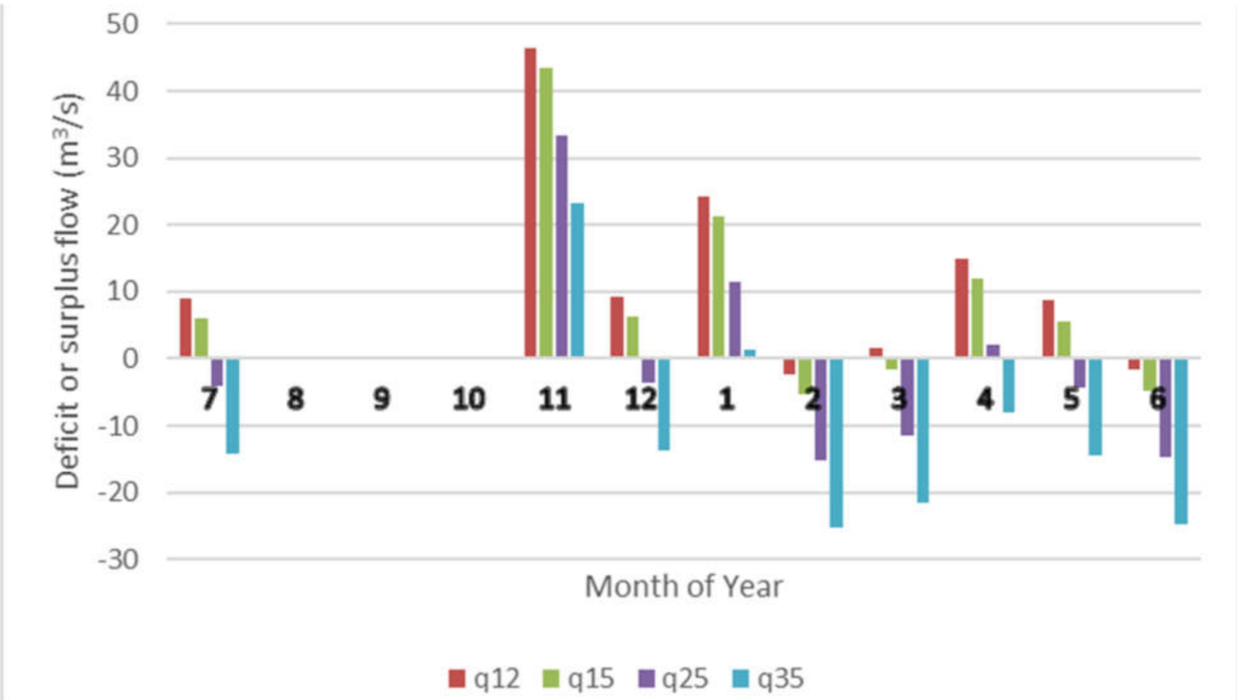


Figure 13 indicates the actual surplus and deficit flows (in m3/s or cumecs) in the months from November to June, but also includes July, as the first half of July has relatively low flows until the monsoons arrive. These are shown only for the dry-season months across the four thresholds.

**Planning a seasonal e-flow regime: what flow modifications may be needed?**

We also noted that sudden flood-season releases from the dam in monsoon could be offset considerably by improving the river flow in June. That way, in the pre-monsoon period, greater buffer capacity may be possible to maintain to store excess runoff from inflows driven by monsoon rainfall. In April, there seems to be an untimely release into the river, which is at variance from the natural flow regime, when water levels should be at their lowest. Such releases could be avoided through better allocation of releases in March and May. In the same way, January releases, which are nearly adequate ecologically, could be allocated to February to overcome the very low water releases in that time, and November releases could be controlled to accommodate December releases. These modifications can maintain better connectivity in the driest months and improve habitat quality for fish species as well.

Overall, throughout the year, the major modifications needed to the flow release pattern from the dam will be as follows: 1) reduction of sharp releases in the monsoon and prior downstream e-flow allocation in June 2) redistribution of January, April, and November flows to February, March-May, and December respectively. It follows that a smoother and gentler water-level rise and fall needs to be ensured even in the flood months, to have adequate storage for dry-season flow allocations (Giri et al. 2019, Shafroth et al. 2010). Figures 14 and 15 show the annual modified e-flow regime and the dry-season changes to achieve e-flow thresholds, respectively.

**Figure 14.** Annual modified e-flow regime for the Pench river downstream of Totladoh dam. The same annual discharge has been re-allocated across months to ensure habitat quality maintenance for the target species, Eurasian Otter.

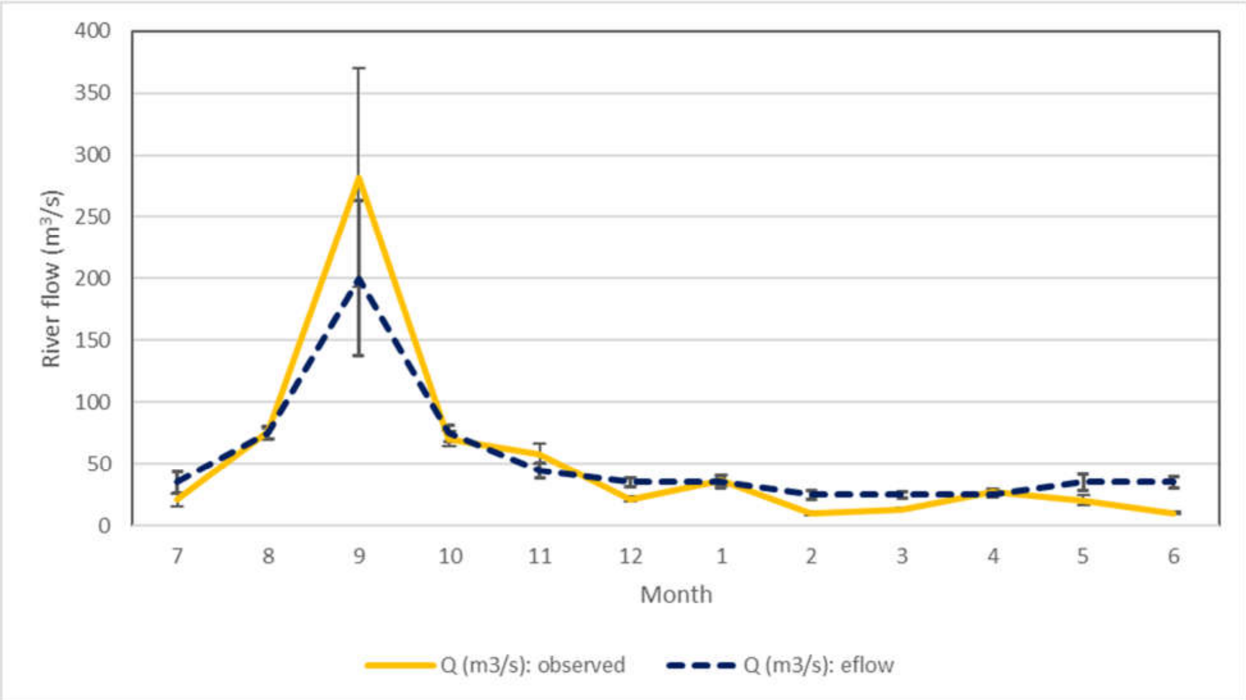
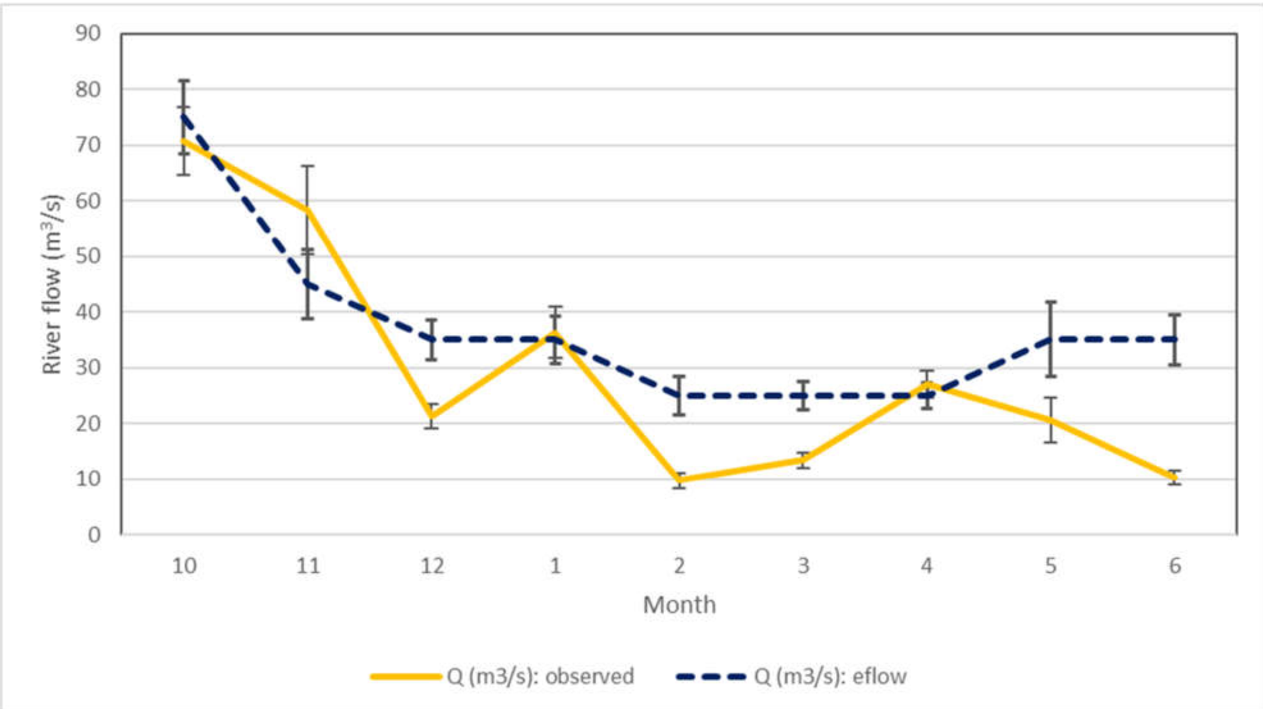



**Figure 15.** Dry-season modifications to downstream flow allocations from Totladoh dam (Oct-June).



***Base flow and persistent habitats: deep pools***

Habitats such as deep pools may persist in a few locations along the Pench river, despite complete stoppage of downstream outflow from the dam. These pools may be sustained by groundwater-contributed base flows into the river channel or seepage from the dam, which is estimated at around 2% of annual reservoir storage. These pools may sustain otters for some part of the season, but not in the most difficult dry-season months in years of drought or high temperatures. Also, ecological flows still remain irreplaceable for ensuring longitudinal connectivity of in-stream habitat for fish and other aquatic organisms. It is important to note this here because a cursory observation of maps may suggest that deep pool habitats are enough, and more flow releases may not be needed. Groundwater depths in the Pench basin are reasonably shallow (Naithani et al. 2014) and groundwater contributions to surface flow in the dry-season will be critical under e-flow operability and modifications are implemented into the dam's standard operating procedures and rule curves. Rule curves can be derived to accommodate multiple objectives, thus allowing optimization of ecological flows with respect to refinement of existing curves (Jain 2019, Chaleeraktrakoon & Chinsomboon 2015, Zhou & Guo 2013). Additionally, protecting the groundwater stocks from potential risks such as excessive evapotranspiration from reforestation (Newman et al. 2006), or construction/tourism-related water supply activities in the periphery of the area, will be important.

A deep pool in the Pench river.

## RECOMMENDATIONS

1. Integration of e-flow provisions in Pench Tiger Reserve management plan: **The proposed annual 'ecological flow regime' needs to be integrated with the Pench Tiger Reserve (MH) management plan under the guiding principle set in Section 29 of the Wildlife (Protection) Act**, which states that "No person shall… divert, stop or enhance the flow of water into or outside the sanctuary, except under and in accordance with a permit granted by the Chief Wild Life Warden, and no such permit shall be granted unless the State Government being satisfied in consultation with the [National Board] that such… change in the flow of water into or outside the sanctuary is necessary for the improvement and better management of wild life therein". Therefore, it is important and opportune that e-flow prescriptions be integrated through the proposed suggestions and prescribed e-flow allocations.

2. **We estimated that during the dry-season, 25 to 35 $m^3/s$ of river flow needs to be maintained in the river downstream of Totladoh dam, for ecologically ideal conditions to be met. The months in which this flow needs to be especially ensured are February, March, May, and June.**

3. **The sharp release of water during August may be dampened a bit by releasing some of the flows in the month of June, in the pre-monsoon period.** This can help achieve ecological flow allocation and also buffer the dam storage against the impact of sudden flash floods or extreme rainfall events, which may create the need for sudden and fast releases and risk the dam gates as well as downstream river ecology. Under climate change, such extreme rainfall events are predicted to increase in frequency and intensity across central India (Roxy et al. 2017, Rajeevan et al. 2008, Goswami et al. 2006).

4. **It is recommended that the Pench TR authorities in Maharashtra install at least one water level recorder and automated sensor system in the middle stretch of the 12 km section from the gates of the Totladoh dam to the backwaters of the Kamthikhairy dam.** The water flow recording system should be digitally telemetered and automated with the capacity to relay river flow and level information in real-time to the central office of the Pench TR (MH) authorities.

5. **It is important for the Pench TR authorities to establish a regular communication channel with the Totladoh dam operating authorities by sharing the real-time information received on the magnitude of flow releases.** If observed river flows become too low or altered, the dam authorities could be requested to provide more flows to meet the ecological requirements of the river by taking necessary action to provide the required flows from Totladoh dam.

6. Engineering studies on dam gate and sluice design will help in potential future fine-scale prescriptions at the supply side to modify dam operations towards ensuring ecological

requirements of the downstream river ecosystem and optimizing irrigation and hydropower generation against ecological flow provisions.

7. **Periodically, otter occurrence and fish abundance in the reference sites along the stretch should be monitored to check if they have responded to improvements in e-flow provisions.** In turn, adaptive assessments of river flow availability, demand, and provisioning scope need to be carried out from time to time to account for future uncertainties in water availability due to rising human demands and climate change.

8. Groundwater contributions to base flows need to be assessed using hydrological methods as well as stable isotope studies to estimate the retention time of base flows, groundwater-surface water feedbacks, and stream flow gains when the dam gates are completely shut.

9. Future increases in water requirements for irrigation and hydropower will affect flow allocations. The Godavari basin management plan identifies the Pench sub-basin as a catchment with potential for further surface irrigation development and hydropower (GoMH-WRD 2017). In this regard, it is essential to have adaptive dam operations that can help in buffering ecological flow provisions against the impacts of rising human demands, especially from urban centres (Sukhwani et al. 2020).

10. Central India is an evolving climate change hotspot and impacts of climate change are being witnessed in the form of sudden and extreme rain events, intensifying droughts, as well as increases in surface water availability due to changing water cycles and local moisture transport. E-flow studies need to be conscious of such sudden effects and provide adequate room for decision-making on concerns of dam safety. E-flow provisions as per prescribed distributions could play a small but significant contribution in buffering the dam from extreme water events.

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