Staverton
742

Archimedean Screw
Hydropower scheme at
Staverton

Hydrology Assessment

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Executive summary

Hydrology of the affected watercourse, the River Dart, is well understood from other local projects, and is here characterised from long-term local flow data. The data is used to model the relative extent of flow changes under the proposed operating regime, which has been intentionally designed so as to have least environmental impact while still allowing a viable hydropower scheme. The proposed regime is as protective as EA default guidance.

Catchment character

The behaviour of the River Dart is well-documented, with a long sequence of gauged flow data available. Flow data for the years 1958-2017 is available from the Environment Agency (EA) Austins Bridge gauging station (ID# 46003), where the Dart's behaviour is considered a *"responsive natural regime"*. The catchment is characterised as follows: "*Responsive catchment with upper two thirds draining moorland associated with Dartmoor Granite; lower third is of Carboniferous shales and sandstones. Steep relief in headwaters and at Granite boundary. Land use is low-grade agriculture and woodland. No major catchment changes.*" *https://nrfa.ceh.ac.uk/data/station/spatial/46003*

Hydrology for hydropower

Energy can be extracted from falling water and harnessed to provide mechanical or electrical power. The theoretical amount of energy available from any given site is directly proportional to two factors: the actual volume of water passing the site (the flow) at any given time, and the height through which the water falls at the site (the head) at that same time. In order to assess the actual potential of this site, it is desirable to understand how the flow and the head vary together over the course of an average year. How much of these physical flows may actually be taken by the hydropower scheme is then the subject of environmental constraints regulated by the EA. The present analysis has taken these factors into account in proposing a suitable scale of hydropower scheme, based on assessing the expected average annual energy capture from the proposed operating conditions and hence also the viability of the scheme.

Data source and adjustments

Using a long data sequence is standard good practice, and Austins Bridge gauge has been recording flows since 1958. The gauging station lies some 7km upstream of the proposed point of abstraction, and its data therefore represents a larger catchment. To modify the Austins Bridge dataset to reflect this different catchment size at Staverton Leat, a multiplier of 1.0427 has been applied, following the same method used at Staverton by the EA in its Habitats Directive Appropriate Assessment of Dart flows for the Dartmoor SAC. (Given the small difference in these areas, no special allowances were made for any difference in rainfall between areas of lower and higher elevation etc.)

Gauged and naturalised flows

The project has assumed that the gauged flows from Austins Bridge are representative. At licensing pre-app, the EA favoured the use of a naturalised version of the Austins Bridge flow data. The EA provided naturalised data from 1990-2016, which tends to give flows which are a few percentage points higher than gauged data. However as this naturalised flow dataset is relatively short, it was compared with the same period of gauged data to ascertain a difference factor for each percentile, then those values were applied as multipliers for the full Austins Bridge dataset 1958-2017. The resulting naturalised dataset differs relatively little from gauged values, and mostly at low flows. Given the limited deviation between the datasets, even at the peak deviation at Q95, given that recent weather patterns seem likely to increasingly suppress flow values in low conditions, and given that using the dataset with lower values is generally more conservative as to actual amounts of water present, there seems little benefit to using the naturalised dataset in this case. The decision rests with the EA.

% of Year	*1958-2017 Raw gauged*
97	1.43
95	1.68
90	2.16
80	3.18
50	7.26
40	9.34
10	26.59
Qmean	11.76
BFIV	0.143

% of Year	*1958-2017 inferred from 1990-2016 Naturalised sequence*
97	1.59
95	1.86
90	2.34
80	3.40
50	7.56
40	9.64
10	27.01
Qmean	12.05
BFIV	0.154

Comparison of values of Qn from gauged and inferred naturalised data (see above)

Influence of abstractions on site flow

The existing local licensed abstraction into Staverton Leat (maximum 120 l/s, no minimum, and in reality low due to set gate aperture) would be subsumed in the new licensed abstraction, so has no influence on flow calculation. No other relevant abstractions are present.

Influence of discharges on site flow

The local consented discharge from Southford (Staverton) STW has an average value of only 1.3 l/s. This is too small to have a measurable impact on predictions. In practice the volume may be concentrated at different times, but this variation is impossible to predict. When running, its influence will tend to increase the leat flow and hence the total site flow.

Flow duration curve

This data is now used in the following analysis to produce a Flow Duration Curve of the expected flows at this site. The data is analysed statistically and broken down into different flow bands, each occurring for 5% of the year. Each band then represents the percentile flow available, or minimum flow in the river for that percentage of the year. For example, Q90 flow means that for 90% of the year the flow is at this level or more. This data is then presented in the form of a Flow Duration Curve, indicating how often a given flow has occurred (see over).

When proposing a hydropower scheme, two important hydrological factors which need to be established are how much water may be taken by the proposed scheme – the Design Flow - and how much water must be left in the river at any time – the Residual Flow.

Residual flow

The installation of a hydro scheme could hypothetically divert all of the water that currently passes over the weir into the hydro system. Protection of the river environment means that this must not happen. Thus the EA seeks to minimise the length of 'depleted reach' created by a scheme. Ensuring that a residual water flow continues to bypass the scheme is achieved by the EA imposing a **minimum** residual flow as a condition of the EA licence. Other factors may increase this amount (see below), but the **minimum residual flow** is a baseline condition below which abstraction will never take place.

EA licensing practice allows that the minimum residual flow is shared between any spills in the depleted channel - e.g. weir crests, sluices, fish easements or fish passes – hence its value is agreed so as to provide minimum flow for those features as well as to protect the form of the channel. Because of this, whenever the hydro runs, even the minimum flow left is sufficient to ensure continued functioning of any fish passes or other required services.

The latest published EA guidance (issued Dec 2013, in force April 2014 to 2016) continues to form the basis on which EA licensing decisions are made. The scheme proposed here is low-head (having a fall of less than 10m) and creates a depleted reach (by bypassing part of the river), so the scheme is not defined as "on-weir". It therefore falls into Table A, the "starting point" for EA flow allocation guidance for hydropower schemes. This proposes that the minimum residual flow is set at the Q95 percentile of the river's annual flow, or Q97 if "high baseflow". The Dart is considered to have medium baseflow; so default guidance here would be a minimum residual flow of Q95, even for a river location such as the Dart which is classified as highly sensitive to abstraction (ASB3). Q95 is a value typically agreed by the EA for most low-head hydro schemes, in the absence of any other special concerns.

The additional protection which EA Table A suggests by default (for schemes not "on-weir") is that, above the agreed minimum, abstractions may only ever take a proportion of the available flow. The default guidance indicates that 35% may be taken without the need to present further evidence. "Higher levels [will] be considered" - up to 100% of flows, even with a depleted reach (Table A), if suitable additional information is presented.

The present scheme proposal is informed by SEPA standard licensing practice in Scottish salmon rivers, as this has been applied to depleted-reach Archimedean screw hydropower schemes which have operated without evidence of detriment using a 50% flow split. One example is the Craigpot (80kW) Archimedean screw scheme – bypassing a depleted reach on the Aberdeenshire Don, with no co-located fish pass and no fish exclusion screening - where the arrangement licensed under this regime has been found to pose no significant harm to salmonids or impact on their migratory movement (Brackley, R. 2016. “Interactions between migrating salmonids and low-head hydropower schemes”. PhD thesis. Glasgow University).

The present scheme proposal is for a 50% flow split after also leaving a minimum residual flow of Q95. The project’s fisheries consultant has concluded that this regime is suitable to protect habitat in and ensure passability of the weir and depleted reach. No flow will be taken in low conditions, only the minority of flow will ever be abstracted at any given time, and the effect of this abstraction will be to marginally suppress flows at Staverton Weir during medium flow conditions. This maintains existing passage flows (by not abstracting) in low-medium conditions, and in higher flows, it will improve passage by reducing overcharging. The fisheries assessment goes into detail to assess the relative impacts of this regime compared with default guidance, and concludes that this regime will confer a marginal improvement. Fish passage and population knowledge on the lower Dart has grown since the Totnes hydropower scheme began operating some years ago, so an earlier concern from EA Fisheries in 2015 asking for further caps on abstraction is now addressed with latest evidence of fish migration vs. flow to support the regime proposed here (report entitled “Staverton Fish Migration Flows”).

Distribution of residual flow

The residual flow will enter the same depleted reach via two primary routes, the new fish pass in the existing easement, and a smaller existing notch or side spill at river left. The side spill, close to the leat intake sluices, has been characterised and its relative flow capacity measured by spot gauging. For this detail, see submitted document entitled “Flow distribution - side channel flow split”. Flow in the fish pass is designed to optimally serve the pass in all conditions, as described in the Fish Pass Approval Application to the EA (please refer). At or below Q95, the fish pass and notch will carry all available flows, until they pass the Q95 flow made up of 1170 l/s in the fish pass and 500 l/s in the side spill. As levels rise above Q95, all further flows will be distributed evenly along the repaired weir crest as well as these routes.

Leat minimum flow

On those occasions when it is necessary to stop flow to the turbine, the project fisheries consultant recommends that a small (20-30 l/s) sweetening flow into the leat should be provided. The status quo is a licensed flow of “no more than” 120 l/s, but NO minimum is specified, so the intake sluices may be fully closed against flood flows, stopping flow in the leat completely. This will continue to be the case, unless the EA wishes now also to condition a minimum flow into the leat. If the EA wishes now to do so, this new requirement would be to improve environmental quality ***outside*** the licensed operation of the hydro scheme; so it is not acceptable that this abstraction should become chargeable to the applicant. Therefore a regulatory solution must be found which ensures no unit charge. If necessary, this can be regulated by a condition in a full abstraction licence or in an impoundment licence: not quantifying the flow as such, but simply requiring the gate to be set with a minimum aperture in all conditions. The minimum aperture value can be subject to written agreement with the EA after field tests to verify what aperture is suitable – e.g. inserting a stop to ensure that the gate never closes to less than 5mm for a high “leakage-like” rate of flow. (Alternatively, as the EA currently holds a full licence for the leat flow and is presumably exempt from a unit charge on this flow, perhaps the EA could retain its own non-chargeable licence specifically for this.)

To provide for the downstream movement of fish in the leat, additional flow (over and above the turbine flow) is not needed. The proposed design is for an Archimedean screw turbine with dimensions meeting EA guidance thresholds, which presents no obstruction to the downstream movement of fish, smaller species, small-to-medium debris, or gravels. Therefore whenever flow is entering the leat during turbine operation, it is expected that fish following this flow into the intake sluices will continue on to the screw and descend the screw. If there are to be occasions when flows into the leat are negligible, i.e. a sweetening flow admitted via a small aperture beneath the closed intake sluice, then there is no opportunity for fish to enter.

No flow is needed to provide for the upstream movement of fish in the leat. Upstream movement of fish into and through the turbine is not possible. It is understood that the EA favours encouraging migratory fish to prefer the more suitable habitat of the main channel, and thereby to reach the easements at the weir. This aspiration is furthered by preventing upstream passage via the leat.

Design flow

EA guidance in Table A indicates that the default maximum for the value of a low-head hydropower abstraction where a depleted reach is created, even on a river of ASB3 sensitivity, could be 1.3x the river's annual mean flow at the site. Present data at this site (as calculated above) gives a mean flow of 11.76 m3/s (~Q32) and a default maximum allowed abstraction of 1.3x Qmean, being 15.28 m3/s (~Q23). An application to abstract up to 15.28 m3/s would therefore fall within the conventional EA guidance without additional justification.

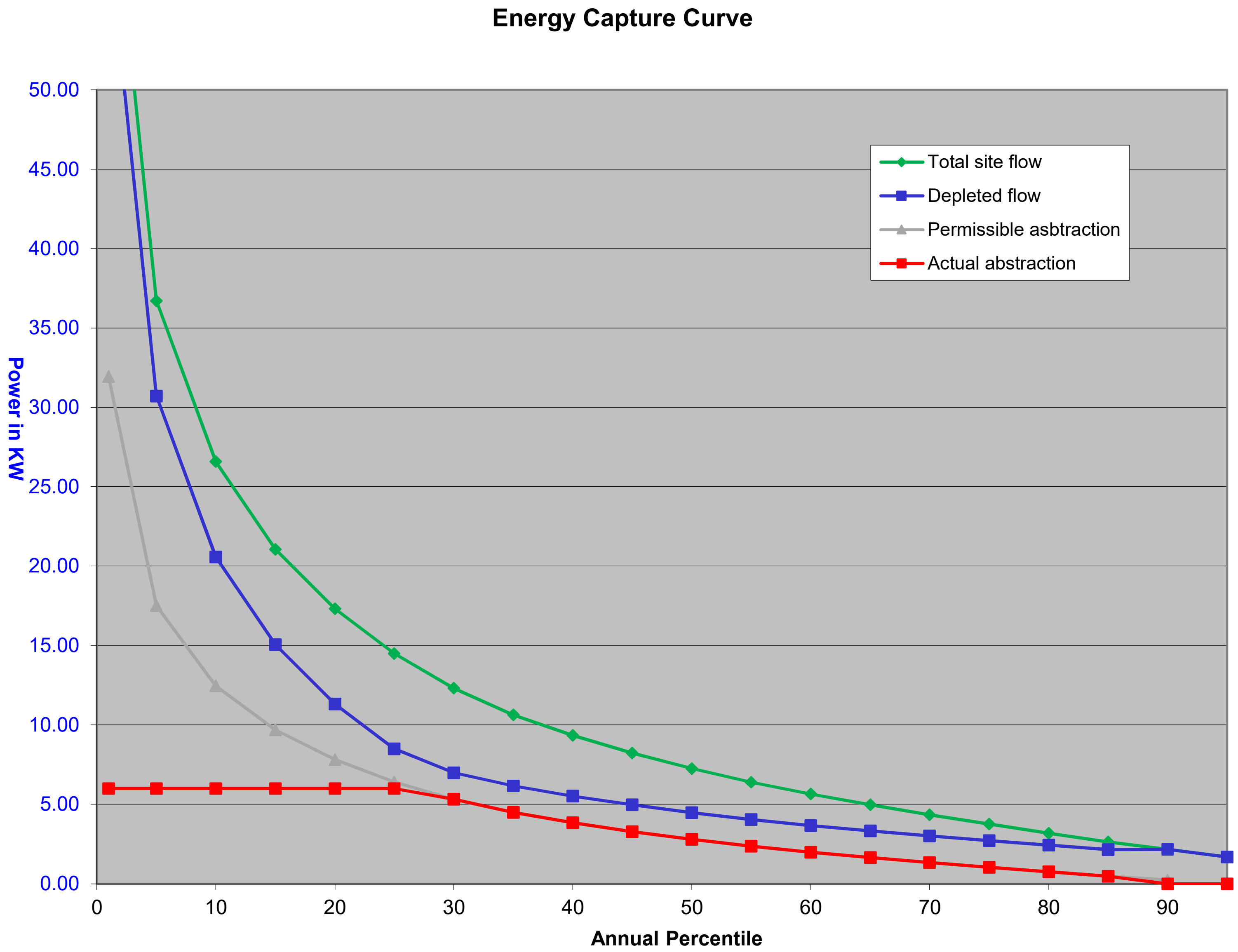
This project, however, seeks a maximum abstraction which is very much less than the river's mean flow, and hence very far within the EA's guidance limits. Proposed maximum abstraction is 6.00 m3/s (equivalent to river's Q58 flow in present data) – and this amount to be taken at peak operation only. An abstraction varying up to this maximum will efficiently supply a hydro scheme of the proposed design which represents economic viability to the applicant.

NB: Where a technical fish pass is proposed to be co-located with the screw, a dedicated minimum flow for this would be calculated in relation to the size of the hydropower abstraction. It is anticipated that a co-located fish pass would not be an acceptable option in this project, as this would ensure that fish moving upstream are encouraged out of the natural channel and into the leat where they must then swim against the hydropower inflow to exit. Therefore this option is not considered. As above, it is anticipated that the EA will favour retaining fish in the main channel, where passable conditions will be preserved and enhanced at the weir.

Presentation of hydrograph

The EA will want to assess the relative impacts of the proposed regime. The figure below provides a hydrograph of the modelled impact of the proposal, having taken into account all factors discussed above. The impact of the modelled proposal on salmon migration is interpreted in the Fisheries Impact Assessment with detailed commentary on the relative effects of this and other potential regimes.

The green line on the curve shows how much water is available in the river. The blue line shows how much is left in the main channel while abstracting. While the grey line shows the extent of abstraction which the regime would theoretically allow, the red line shows the actual amount which would be abstracted, which is constrained by the turbine's maximum capacity (in higher flows). Abstraction cannot take place in lowest flows due to an agreed value of minimum residual flow. Productive output then depends on area beneath the red line.


Energy Capture Curve
Power in KW
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
80
90
Annual Percentile
Total site flow
Depleted flow
Permissible asbtraction
Actual abstraction

When compared with EA default guidance, the proposed regime appears to create no greater impact in high flows, and leaves the same water in the river in lowest flows – so on balance does not create a significantly different detriment than the EA's default guidance.

For the proposed regime, source data is presented in tabular form.

Flow Data in m3/s	BEFORE	AFTER			Proposed regime:		
Q%	Gauging station flow	Total site flow	Depleted site flow	Minimum residual flow	Permissible abstraction	Actual abstraction	% abstracted	% left in river
1	62.86	65.55	59.55	33.61	31.93	6.00	9%	91%
5	35.20	36.70	30.70	19.19	17.51	6.00	16%	84%
10	25.50	26.59	20.59	14.13	12.46	6.00	23%	77%
15	20.20	21.06	15.06	11.37	9.69	6.00	28%	72%
20	16.60	17.31	11.31	9.49	7.82	6.00	35%	65%
25	13.90	14.49	8.49	8.09	6.41	6.00	41%	59%
30	11.80	12.30	6.99	6.99	5.31	5.31	43%	57%
35	10.20	10.64	6.16	6.16	4.48	4.48	42%	58%
40	8.96	9.34	5.51	5.51	3.83	3.83	41%	59%
45	7.90	8.24	4.96	4.96	3.28	3.28	40%	60%
50	6.96	7.26	4.47	4.47	2.79	2.79	38%	62%
55	6.14	6.40	4.04	4.04	2.36	2.36	37%	63%
60	5.41	5.64	3.66	3.66	1.98	1.98	35%	65%
65	4.76	4.96	3.32	3.32	1.64	1.64	33%	67%
70	4.16	4.34	3.01	3.01	1.33	1.33	31%	69%
75	3.60	3.75	2.72	2.72	1.04	1.04	28%	72%
80	3.05	3.18	2.43	2.43	0.75	0.75	24%	76%
85	2.52	2.63	2.15	2.15	0.47	0.47	18%	82%
90	2.07	2.16	2.16	1.92	0.24	0.00	0%	100%
95	1.61	1.68	1.68	1.68	0.00	0.00	0%	100%

Interpretative notes:

- Flow at the site intake (green) is derived by area ratio from gauging station flow.
- The proposed regime (blue) follows the formula "50/50 after having left Q95".
- Hydropower abstraction only takes place at flows above Q95 (red).
- The EA licence will also specify the maximum instantaneous abstraction (6.00 m3/s), which recognises that the proposed scheme size takes far less than 50/50 at higher flows (red %).

Changed flow distribution

Assessment by the fisheries consultant (see reports) has concluded that the proposed flows are suitable to provide the necessary services at all points in the depleted reach, including that the weir itself will be passable over a suitable designed range.

The proposed regime of Q95 plus 50% retains a naturalistic variation in levels and flows. This ensures that rising velocities continue to be provided in the main channel, as behavioural cues or signals to alert migrants to rising flow events upstream which may prompt them to move; and that higher flows continue to operate to mobilise bedload and woody debris. At the same time, the regime suppresses more challenging effects of high flows for upstream migrants.

The potential for the proposed flow changes to significantly affect hydromorphology is thus considered likely to be low. This subject is given fuller consideration in a dedicated report.

Method of controlling the proposed regime

The “hands-off” condition would be controlled by a conventional electronic level sensor (submerged pressure transducer), connected to the control system and operating to ensure that the hydropower scheme could not begin or continue to abstract unless the proxy water level for minimum residual flow could be maintained. The scheme’s control system includes a PLC (Programmable Logic Controller) to program and execute all aspects of system control, including constantly monitoring the sensor input. This method is designed to be failsafe, in that component failure or loss-of-signal from the sensor/s will cause the system to stop. In all conditions above minimum, the system would record instantaneous flow in the turbine itself, and continuously compare this with river levels to ensure compliance with the agreed percentage flow split. This method has been operating successfully for some years in other similar UK schemes where a proportional take regime is in force (e.g. Aberdeen Community Energy scheme at Donside; Brahan Estate).

To achieve the above, it is necessary to derive an equation which allows water levels to be satisfactorily converted into flow values. This can be done via field testing at commissioning using the system sensors, prior to commencing hydropower abstraction; or by deploying other data loggers prior to construction. Either of these programmes of water level monitoring will give a stage-discharge relationship which will form the basis of the control equation at this site. The logged data of levels is converted to mAOD using site datum, then graphed and overlaid on a graph of the same events seen in the 15-minute flow data sequence from Austins Bridge gauging station, to adjust for time elapsed between measuring locations. The Austins Bridge flow values for this period are then assigned Qn percentile values based on analysis of the longer-term Austins Bridge dataset. The dataset is then ordered and graphed to produce a trendline equation of the relationship between any given level and the corresponding main channel flow which that level represents. Then another relationship is obtained for water level at each value of DEPLETED main channel flow – i.e. whenever the screw is taking its share as per agreed regime.

The PLC continuously monitors the water level input and applies the equation to calculate the flow in the main channel of the river, checks an agreed parameter to decide when the system may start abstracting, sets the screw speed to take a specific flow, continuously checks a second equation to confirm that total flow (river + turbine) is compliant with the instantaneous water level, and adjusts the speed up or down to suit.

A licence condition will be acceptable to the effect that, prior to operation, written approval must be gained for the stage-discharge relationship to be established as above.

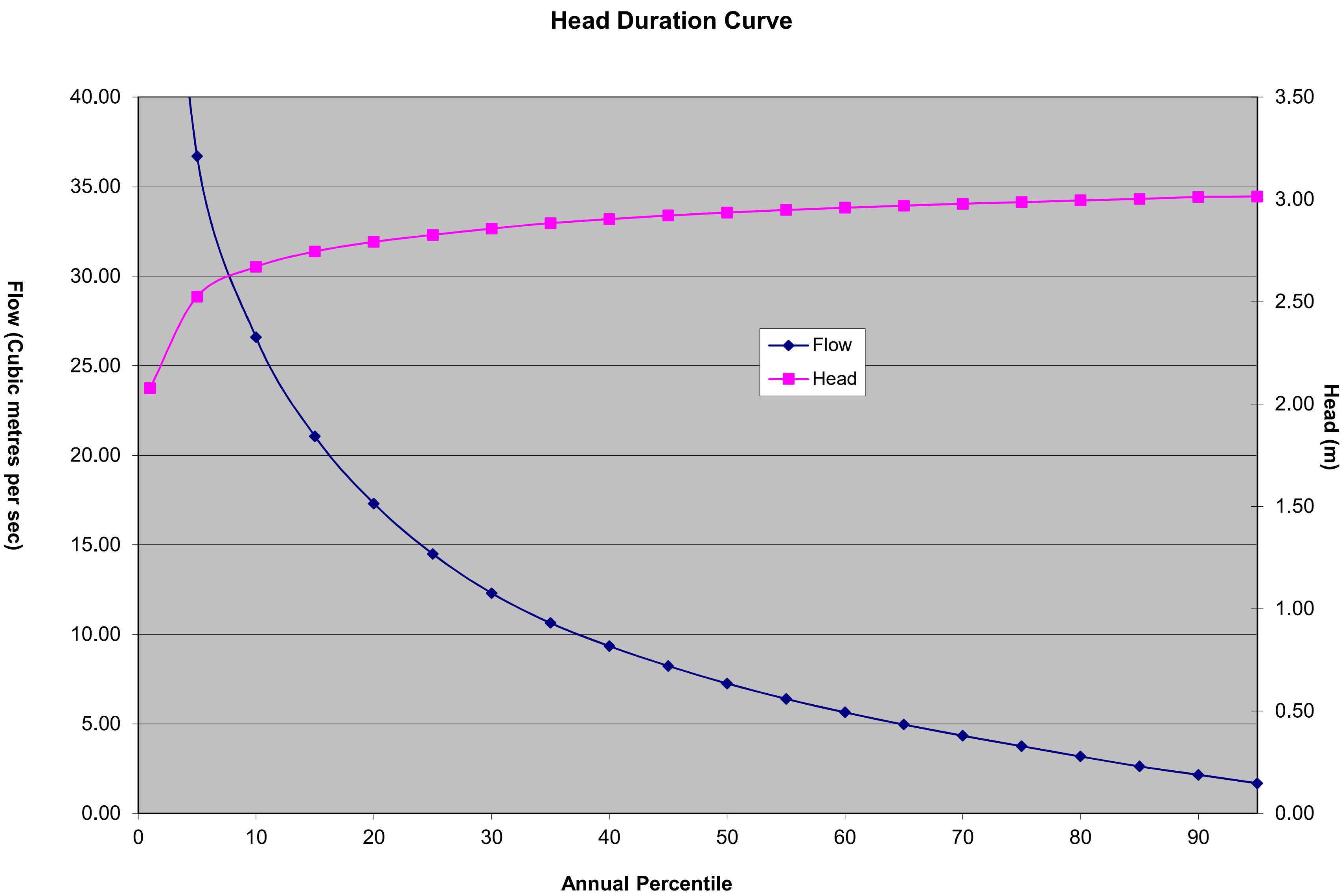
Cumulative impacts and lifecycle impacts

There are no cumulative impacts on hydrology, as the scheme's effect ceases at the point of discharge. In lifecycle terms, hydrological impacts of the project are largely limited to its operational lifespan. Construction in the river involves only small temporary cofferdams for weir improvements, with the other works being carried out offline within the leat. Decommissioning of the project at some future stage requires only the dismantling of a subset of steel mechanical parts from the offline channel. The screw's sluice gate can then be left in place, lowered, if it is desired to continue holding water in the leat as if the turbine was at rest; or it can be raised or removed, if it is desired to return the leat to a shallow flow as at present. The river itself will need no remediation. After cessation, all flows then remain in the river channel and/or the agreed sweetening flow will continue in the leat if so desired.

Head duration curve

The height that the water falls over the hydropower site is known as the head. This varies with the flow in the river. Site measurements have indicated a gross head of 3.05m between the water levels at the intake and discharge, in conditions representative of lower flows. Having then allowed for intake design and losses, the net head available is some 2.40m for an Archimedean screw turbine, reducing gradually as the tailwater rises in higher conditions.

Effect of likely tailwater rise at this site, based on sites of similar geometry, is presented in an indicative graph below for gross head. As the river flow increases (blue) towards the left, the head decreases (pink). Head does not diminish to zero until close to bank-full conditions.



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