# Impacts and mitigation for micro-hydropower developments in Wales

Gideon Carpenter

Natural Resources Wales

# So what are the main impacts?

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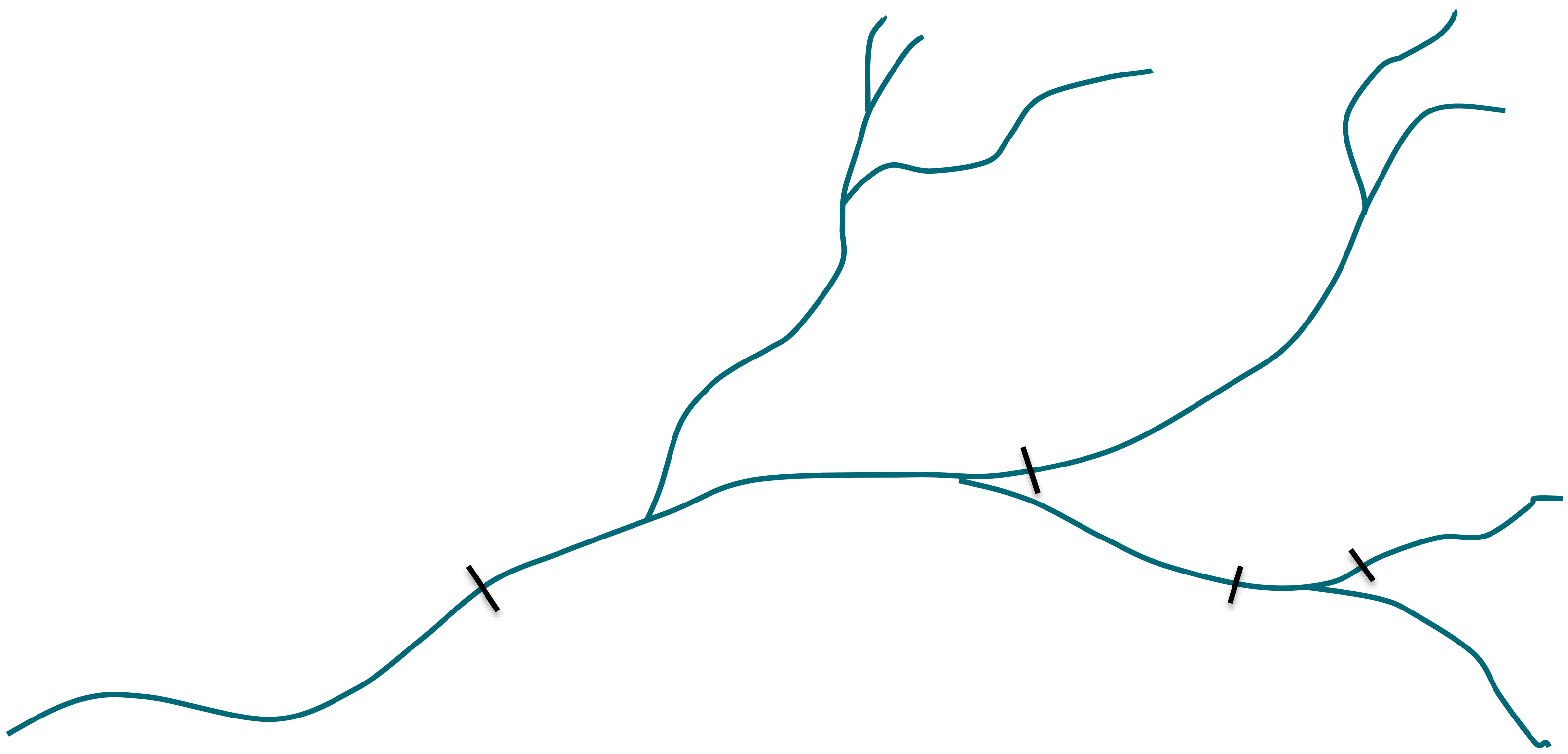
- **Creation of physical barrier**
  - Fragmentation of ecosystem
  - Disruption of ecosystem connectivity
  - Disruption of geomorphological processes
- **Changes to reach hydrology**
  - Creation of impoundment
  - Creation of depleted reach
  - Changes to hydraulic conditions (depths, velocities, wetted perimeter)
- **Changes to physical habitat & channel morphology**
- **Physical damage to fish (& other wildlife)**

# Disruption to ecosystem connectivity and spatial extent of impact



# What mitigation can we apply?

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- Fish passes & easements
- Protective environmental flow regime
- Geomorphologically sensitive siting & design
- Screening

# Formal fish passes

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# Fish easement

# Fish passage summary

- Approval required for formal fish passes
- They require detailed technical design
- They can be complex and expensive to build
- Fish easements may be acceptable on smaller schemes
- Fish passes are not 100% efficient
- Fish lost from system
- Cumulative impact of multiple barriers

# Hydrological impacts

**To understand hydrological impacts you will need to understand:**

- **Natural flow regimes**
- **Hydropower abstraction regimes**
- **Hydrological setting of schemes**

# Impacts of hydrological change - conceptual model

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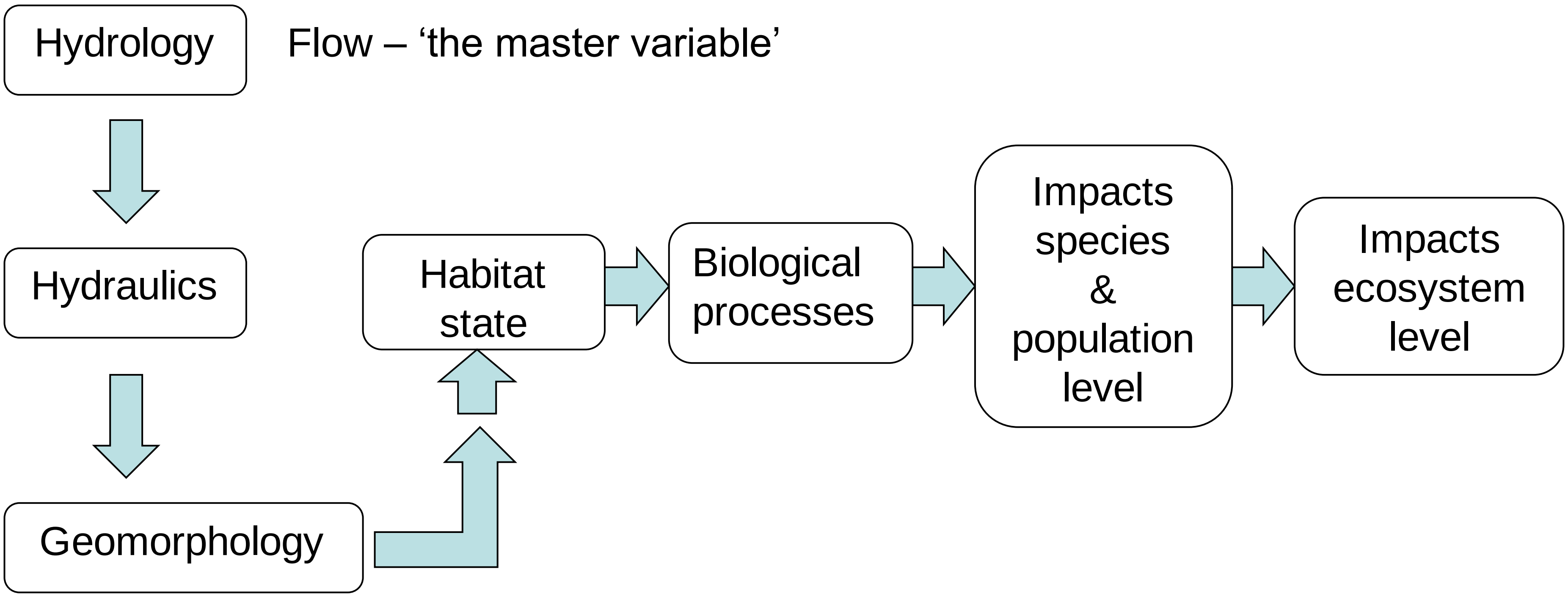


Source: Ecological indicators of the effects of abstraction and flow regulation and optimisation of flow release from water storage reservoirs WFD 21d SNIFFER 2012

# Ecological Limits to Hydrological Alteration

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Uncertainty in quantifying river flow-ecology relationships

BUT

Ecosystems adapted to natural flow regimes

↓

Restrict deviations from the natural flow regime

↓

Ecological Limits to Hydrological Alteration (ELOHA)

# Approach

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Hydrology as surrogate for Biology

↓

Approach - Limits to hydrological alteration

↓

What measure? – Richters Indicators of hydrological alteration.

↓

ELOHA – how far can you go?

What standards? Assessing deviation

# Indicators of hydrological alteration (IHAs)

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- **Quantify components of the hydrograph**
- **Timing – frequency – magnitude – duration**
- **WFD risk thresholds for deviation**

**UKTAG Standards (Water Framework Directive Report 82)**

- 0-10% for protected areas and HES.
- 10-40% low risk of failing to achieve GES
- 40-80% moderate risk
- >80% high risk

# Flow standards – NRW Guidance

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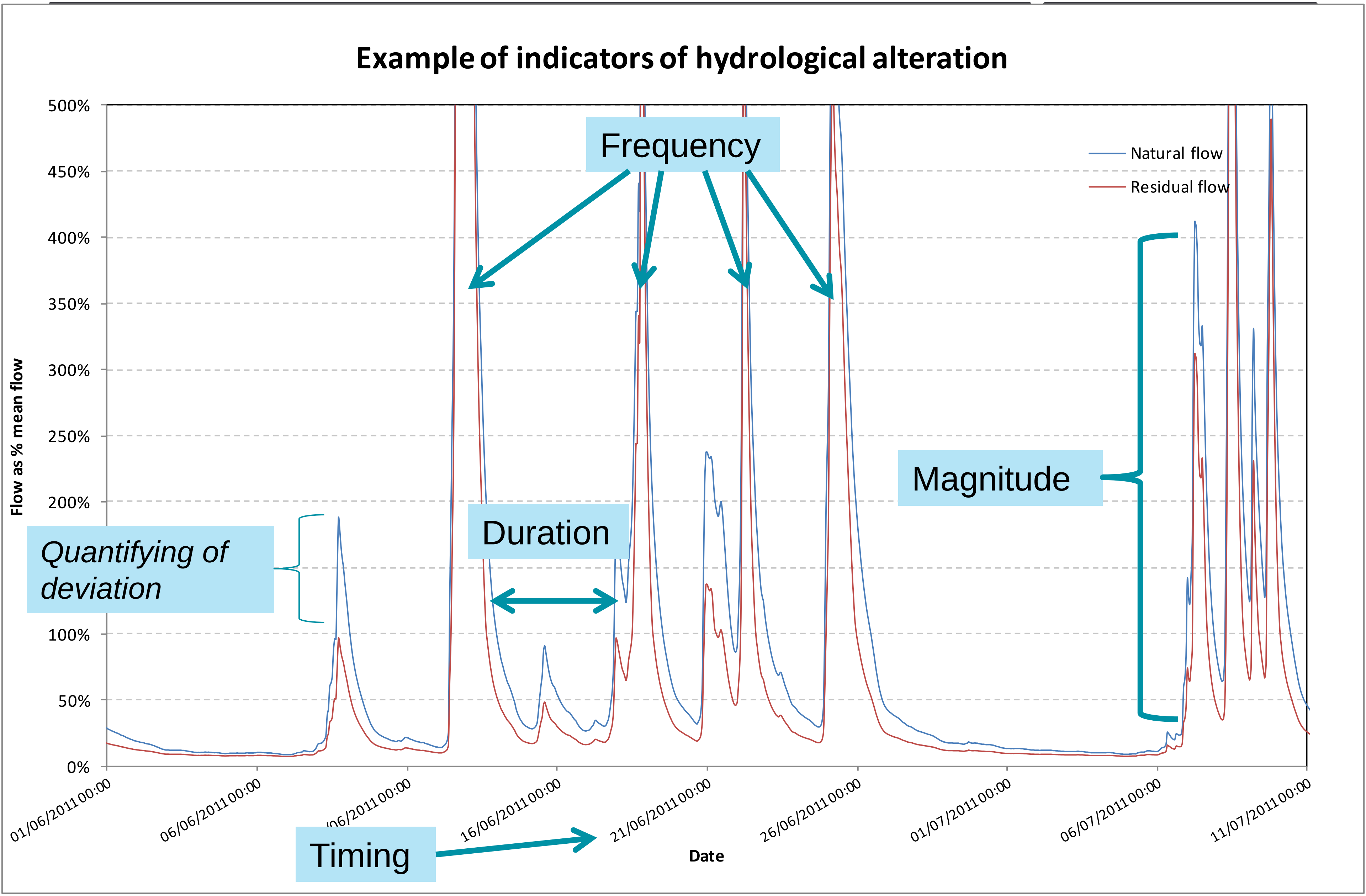
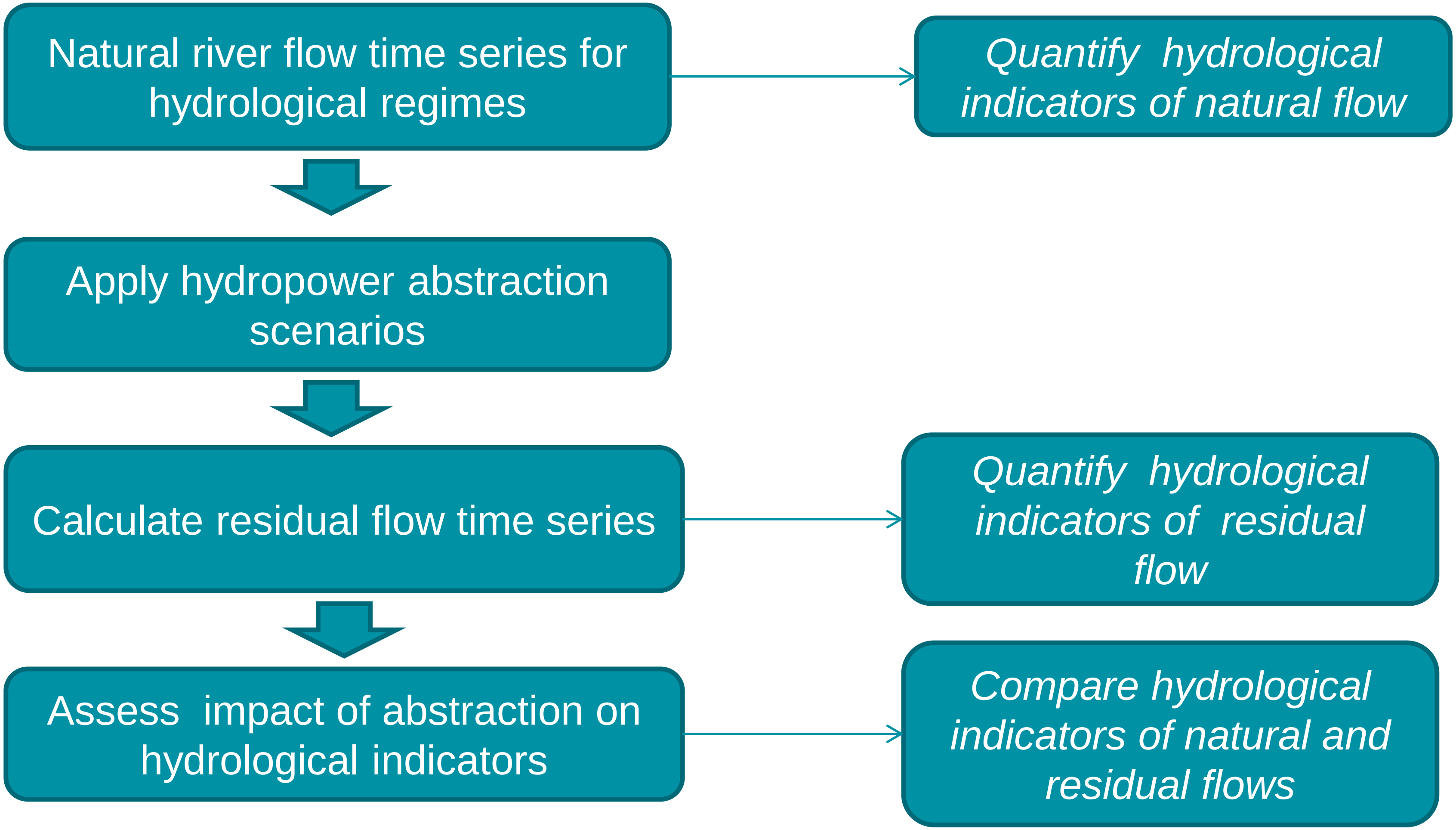
## Convert ecological requirements into residual flow regime via licence conditions

- Low flow protection – usually Q95 – low summer flow
- Flow variability – % take of available flow
- Protection of peak flows – max abstraction as proportion of Qmean



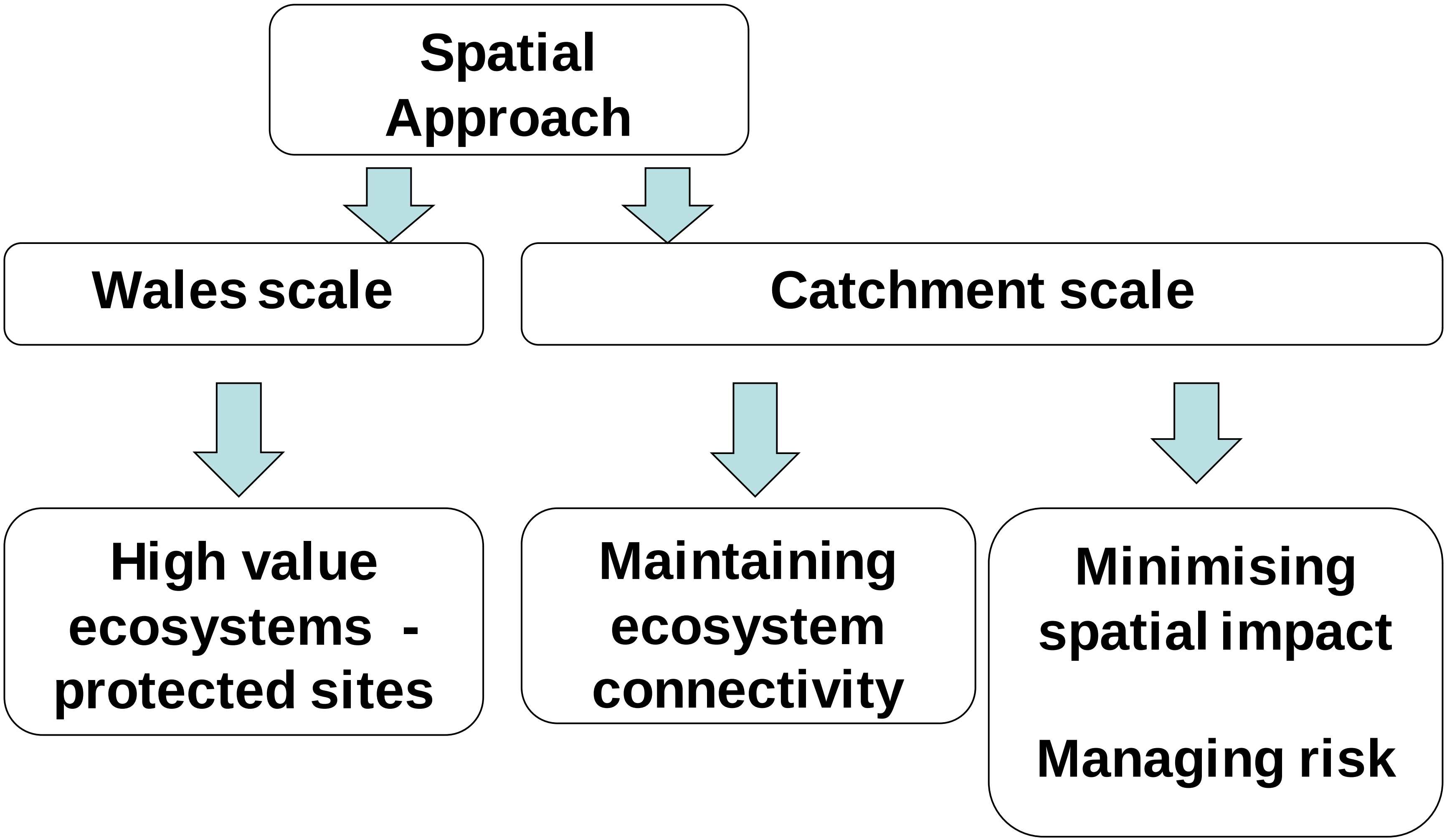
Example of indicators of hydrological alteration
Flow as % mean flow
500%
450%
400%
350%
300%
250%
200%
100%
50%
0%
Natural flow
Residual flow
Frequency
Magnitude
Duration
Quantifying of deviation
Timing
01/06/2011 00:00
06/06/2011 00:00
16/06/2011 00:00
21/06/2011 00:00
26/06/2011 00:00
01/07/2011 00:00
06/07/2011 00:00
11/07/2011 00:00
Date

# Hydrological modelling



| Ref | 1998-2006 | 2009-2013 | 1998-2006 | 2009-2013 | 1998-2006 | 2009-2013 | 1998-2006 | 2009-2013 | 1998-2006 | 2009-2013 | 1998-2006 | 2009-2013 | 1998-2006 | 2009-2013 | Average PoR | Averag e PoR | Averag e PoR | Average PoR | Average PoR | Average PoR | Average PoR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HoF | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 | Q95 |
| % take | 40 | 40 | 50 | 50 | 60 | 60 | 70 | 70 | 80 | 80 | 90 | 90 | 100 | 100 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Max abs | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean | 1.3 x Qmean |
| **Group 1: Magnitude of monthly water conditions** | | | | | | | | | | | | | | | | | | | | | |
| **January - mean** | -25% | -23% | -28% | -27% | -31% | -31% | -34% | -34% | -36% | -37% | -39% | -39% | -40% | -42% | -24% | -28% | -31% | -34% | -37% | -39% | -41% |
| February - mean | -28% | -23% | -34% | -28% | -40% | -34% | -45% | -39% | -49% | -43% | -53% | -47% | -57% | -51% | -26% | -31% | -37% | -42% | -46% | -50% | -54% |
| March - mean | -24% | -24% | -29% | -30% | -34% | -36% | -38% | -41% | -42% | -46% | -45% | -51% | -49% | -55% | -24% | -30% | -35% | -39% | -44% | -48% | -52% |
| **April - mean** | -29% | -26% | -36% | -30% | -42% | -35% | -48% | -39% | -53% | -43% | -58% | -47% | -63% | -50% | -27% | -33% | -39% | -44% | -48% | -52% | -56% |
| May - mean | -25% | -24% | -31% | -30% | -36% | -36% | -41% | -41% | -46% | -46% | -50% | -50% | -54% | -55% | -25% | -31% | -36% | -41% | -46% | -50% | -54% |
| June - mean | -23% | -20% | -28% | -24% | -32% | -28% | -36% | -31% | -40% | -35% | -43% | -38% | -46% | -40% | -22% | -26% | -30% | -34% | -37% | -40% | -43% |
| **July - mean** | -28% | -26% | -34% | -31% | -39% | -35% | -43% | -39% | -48% | -42% | -51% | -46% | -55% | -49% | -27% | -32% | -37% | -41% | -45% | -48% | -52% |
| August - mean | -26% | -23% | -30% | -27% | -34% | -31% | -38% | -35% | -41% | -39% | -45% | -42% | -47% | -45% | -24% | -29% | -33% | -36% | -40% | -43% | -46% |
| September - mean | -25% | -26% | -29% | -31% | -33% | -35% | -36% | -39% | -39% | -43% | -42% | -46% | -44% | -49% | -25% | -30% | -34% | -38% | -41% | -44% | -46% |
| **October - mean** | -24% | -27% | -27% | -32% | -30% | -37% | -33% | -41% | -36% | -45% | -38% | -49% | -39% | -52% | -25% | -30% | -34% | -37% | -40% | -43% | -46% |
| November - mean | -28% | -24% | -32% | -28% | -36% | -32% | -40% | -36% | -43% | -39% | -46% | -41% | -48% | -44% | -26% | -30% | -34% | -38% | -41% | -44% | -46% |
| December - mean | -25% | -26% | -29% | -30% | -33% | -34% | -36% | -37% | -38% | -40% | -41% | -43% | -43% | -45% | -25% | -30% | -33% | -36% | -39% | -42% | -44% |
| **Group 2: Magnitude and duration of annual extremes** | | | | | | | | | | | | | | | | | | | | | |
| 1 day minimum flow | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 1 day maximum flow | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 3 day minimum flow | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 3 day maximum flow | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 7 day minimum flow | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 7 day maximum flow | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% | -3% |
| 30 day minimum flow | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% | -4% |
| 30 day maximum flow | -6% | -5% | -6% | -5% | -6% | -5% | -6% | -5% | -6% | -5% | -6% | -5% | -6% | -5% | -5% | -5% | -5% | -5% | -5% | -5% | -5% |
| 90 day minimum flow | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% | -9% |
| 90 day maximum flow | -18% | -13% | -18% | -14% | -18% | -15% | -18% | -15% | -18% | -15% | -18% | -15% | -18% | -16% | -16% | -16% | -16% | -17% | -17% | -17% | -17% |
| Group 4: Frequency and duration of high and low flow pulses (flows above Qn25 and below Qn75) | | | | | | | | | | | | | | | | | | | | | |
| Number of high flow pulses | 0% | 0% | 0% | 0% | 338% | 0% | 401% | 412% | 451% | 499% | 518% | 540% | 504% | 583% | 0% | 0% | 163% | 407% | 475% | 529% | 543% |
| Number of low flow pulses | 0% | 0% | 0% | 0% | -72% | 0% | -69% | -76% | -63% | -71% | -53% | -63% | -48% | -56% | 0% | 0% | -36% | -72% | -67% | -58% | -52% |
| Duration of high flow pulse | 31% | 7% | 18% | 7% | 24% | 11% | 24% | 9% | 24% | 9% | 24% | 9% | 24% | 9% | 19% | 13% | 18% | 16% | 16% | 16% | 16% |
| Duration of low flow pulse | -55% | -46% | -60% | -55% | -65% | -66% | -65% | -66% | -65% | -66% | -65% | -66% | -65% | -66% | -50% | -57% | -65% | -66% | -66% | -66% | -66% |
| **Group 6: Median and skew of monthly flows** | | | | | | | | | | | | | | | | | | | | | |
| **January - median** | -37% | -18% | -46% | -31% | -55% | -39% | -64% | -46% | -74% | -53% | -82% | -62% | -92% | -79% | -27% | -38% | -47% | -55% | -63% | -72% | -86% |
| February - median | -29% | -4% | -39% | -15% | -48% | -28% | -56% | -38% | -62% | -47% | -72% | -55% | -84% | -73% | -16% | -27% | -38% | -47% | -54% | -63% | -79% |
| March - median | -22% | 0% | -33% | 0% | -43% | -2% | -51% | -10% | -60% | -19% | -69% | -26% | -82% | -40% | -11% | -17% | -22% | -31% | -39% | -47% | -61% |
| **April - median** | -25% | 0% | -34% | 0% | -43% | -12% | -51% | -21% | -59% | -29% | -70% | -38% | -82% | -60% | -12% | -17% | -27% | -36% | -44% | -54% | -71% |
| May - median | 0% | 0% | 0% | 0% | 0% | -12% | -5% | -23% | -11% | -32% | -17% | -42% | -30% | -61% | 0% | 0% | -6% | -14% | -22% | -29% | -45% |
| June - median | 0% | 0% | -12% | 0% | -24% | -2% | -34% | -11% | -44% | -20% | -54% | -30% | -70% | -47% | 0% | -6% | -13% | -22% | -32% | -42% | -58% |
| **July - median** | -1% | -13% | -14% | -26% | -25% | -36% | -33% | -45% | -42% | -54% | -51% | -65% | -71% | -78% | -7% | -20% | -31% | -39% | -48% | -58% | -74% |
| August - median | -19% | -12% | -32% | -23% | -40% | -33% | -47% | -42% | -56% | -51% | -64% | -61% | -80% | -78% | -15% | -28% | -37% | -45% | -53% | -62% | -79% |
| September - median | -30% | -12% | -40% | -23% | -49% | -35% | -57% | -44% | -64% | -53% | -72% | -63% | -83% | -78% | -21% | -32% | -42% | -50% | -59% | -68% | -80% |
| **October - median** | -36% | -30% | -45% | -40% | -54% | -48% | -63% | -56% | -72% | -63% | -79% | -71% | -87% | -85% | -33% | -42% | -51% | -59% | -67% | -75% | -86% |
| November - median | -36% | -35% | -45% | -44% | -54% | -53% | -64% | -62% | -73% | -70% | -80% | -77% | -91% | -88% | -36% | -45% | -54% | -63% | -71% | -78% | -90% |
| December - median | -36% | -36% | -45% | -45% | -54% | -53% | -63% | -62% | -72% | -70% | -80% | -77% | -90% | -85% | -36% | -45% | -54% | -63% | -71% | -79% | -88% |
| S50 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| S80 | 37% | 10% | 59% | 26% | 85% | 47% | 95% | 68% | 104% | 73% | 122% | 80% | 205% | 141% | 23% | 43% | 66% | 81% | 89% | 101% | 173% |
| SK1/SKDF Annual | 40% | 21% | 40% | 44% | 45% | 65% | 60% | 78% | 78% | 79% | 95% | 87% | 188% | 156% | 31% | 42% | 55% | 69% | 78% | 91% | 172% |
| SK1/SKDF Jan | 40% | 4% | 65% | 17% | 77% | 38% | 76% | 45% | 77% | 46% | 95% | 43% | 165% | 87% | 22% | 41% | 58% | 61% | 61% | 69% | 126% |
| SK1/SKDF Feb | 29% | 0% | 45% | 0% | 44% | 2% | 45% | 12% | 50% | 22% | 59% | 17% | 102% | 17% | 14% | 22% | 23% | 28% | 36% | 38% | 60% |
| SK1/SKDF Mar | 33% | 0% | 50% | 0% | 58% | 14% | 57% | 27% | 56% | 41% | 78% | 53% | 137% | 94% | 17% | 25% | 36% | 42% | 49% | 65% | 116% |
| SK1/SKDF April | 0% | 0% | 0% | 0% | 0% | 14% | 6% | 30% | 12% | 48% | 11% | 67% | 7% | 107% | 0% | 0% | 7% | 18% | 30% | 39% | 57% |
| SK1/SKDF May | 0% | 0% | 14% | 0% | 31% | 2% | 51% | 12% | 77% | 26% | 118% | 33% | 192% | 45% | 0% | 7% | 17% | 32% | 51% | 75% | 118% |
| SK1/SKDF June | 1% | 16% | 16% | 35% | 33% | 57% | 50% | 81% | 68% | 119% | 77% | 158% | 139% | 237% | 8% | 26% | 45% | 65% | 93% | 117% | 188% |
| SK1/SKDF July | 24% | 13% | 47% | 30% | 64% | 39% | 69% | 39% | 73% | 37% | 79% | 39% | 138% | 91% | 18% | 39% | 51% | 54% | 55% | 59% | 114% |
| SK1/SKDF August | 44% | 14% | 68% | 30% | 95% | 53% | 119% | 79% | 139% | 93% | 163% | 113% | 221% | 178% | 29% | 49% | 74% | 99% | 116% | 138% | 200% |
| SK1/SKDF Sept | 56% | 43% | 82% | 66% | 101% | 77% | 122% | 82% | 156% | 92% | 200% | 102% | 227% | 171% | 50% | 74% | 89% | 102% | 124% | 151% | 199% |
| SK1/SKDF Oct | 38% | 47% | 38% | 41% | 43% | 43% | 57% | 54% | 75% | 67% | 87% | 72% | 162% | 136% | 42% | 39% | 43% | 56% | 71% | 79% | 149% |
| SK1/SKDF Nov | 53% | 55% | 52% | 80% | 54% | 108% | 60% | 129% | 79% | 155% | 108% | 194% | 190% | 188% | 54% | 66% | 81% | 94% | 117% | 151% | 189% |
| SK1/SKDF Dec | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

# Ecosystems and spatial approach



# Spatial impact of HEP

# Zoning: Channel location & typology

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## What are we trying to achieve? – the principles

- Zones 1, 2 & 3
- Indicative mitigation based on importance for nature conservation and gradient

- Protecting our most important sites
- Maintaining connectivity
- Limiting spatial impact
- Recognizing flashy upland hydrological regimes
- Opportunity to simplify determination process

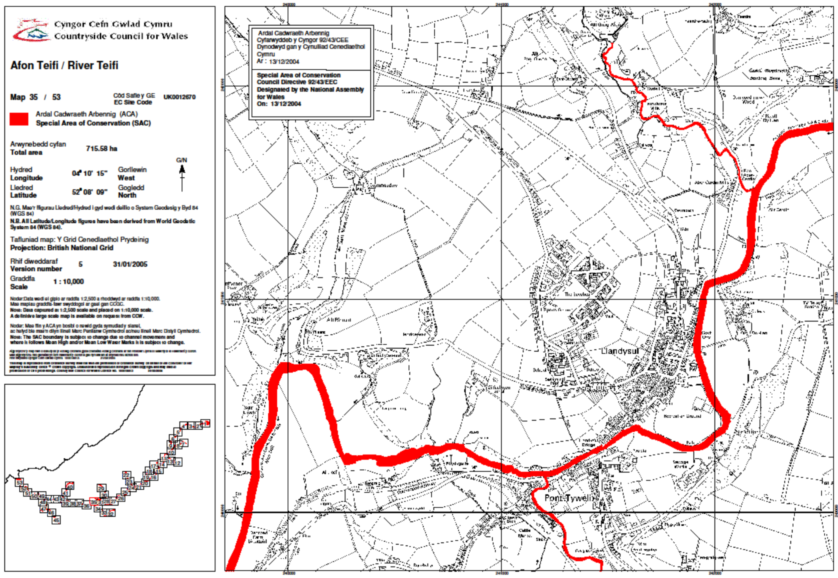
# Zone 1. Designated sites, protected species & supporting habitat

## Designated sites inc:

- Special Areas of Conservation
- Sites of Special Scientific Interest

## Supporting habitat for mobile SAC features - salmon

## Rare species – crayfish, freshwater pearl mussel



# Depleted reach gradient

**Basic proxy for range of physical characteristics:**

- Location in catchment
- Catchment size
- Depleted reach geomorphology
- Catchment type (headwater/lowland)
- Hydrological regime (flashiness)

# Management Zones 2 & 3

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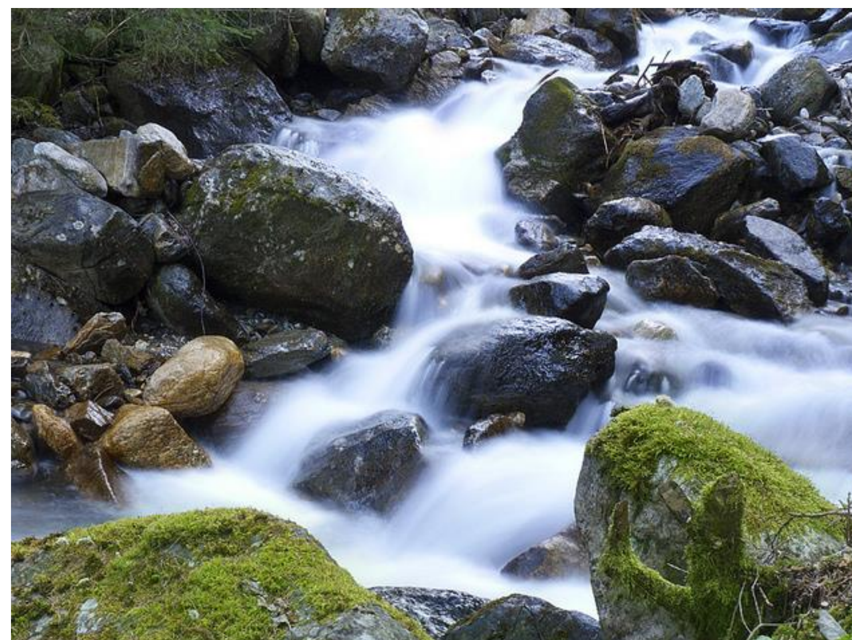
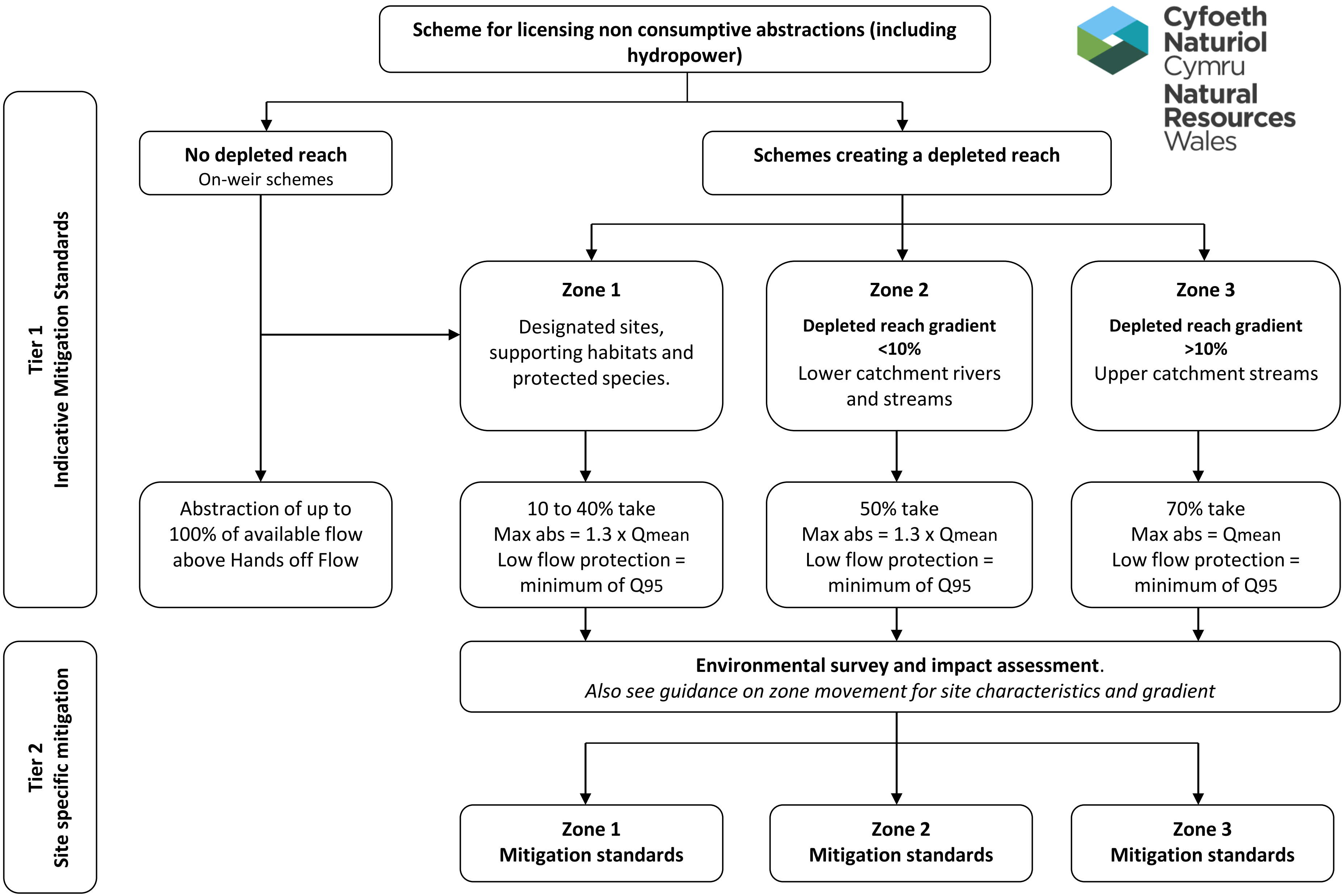
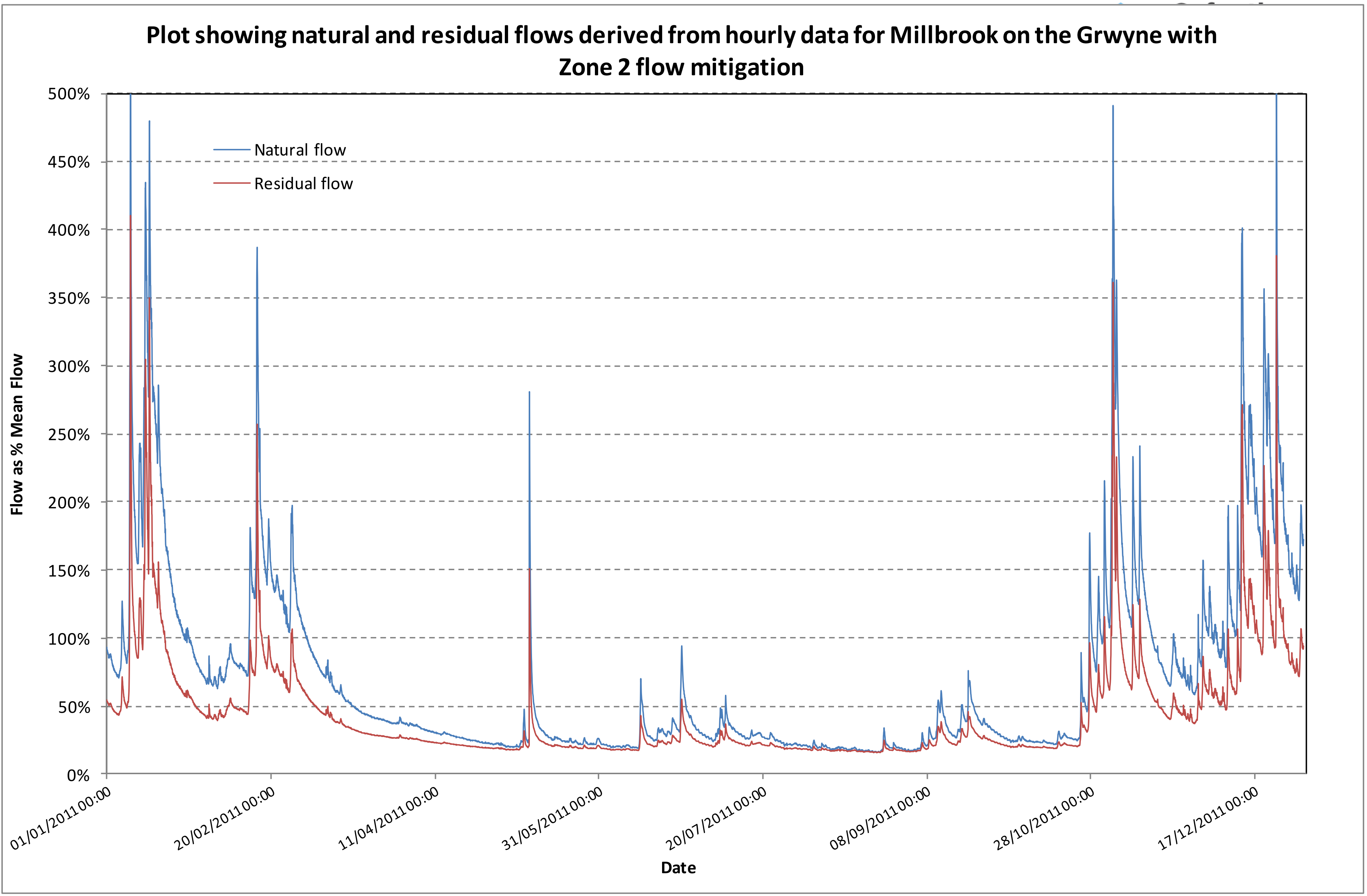
## Based on simple geomorphological classification.

| Zone 2 | Zone 3 |
|---|---|
| <10% gradient | >10% gradient |

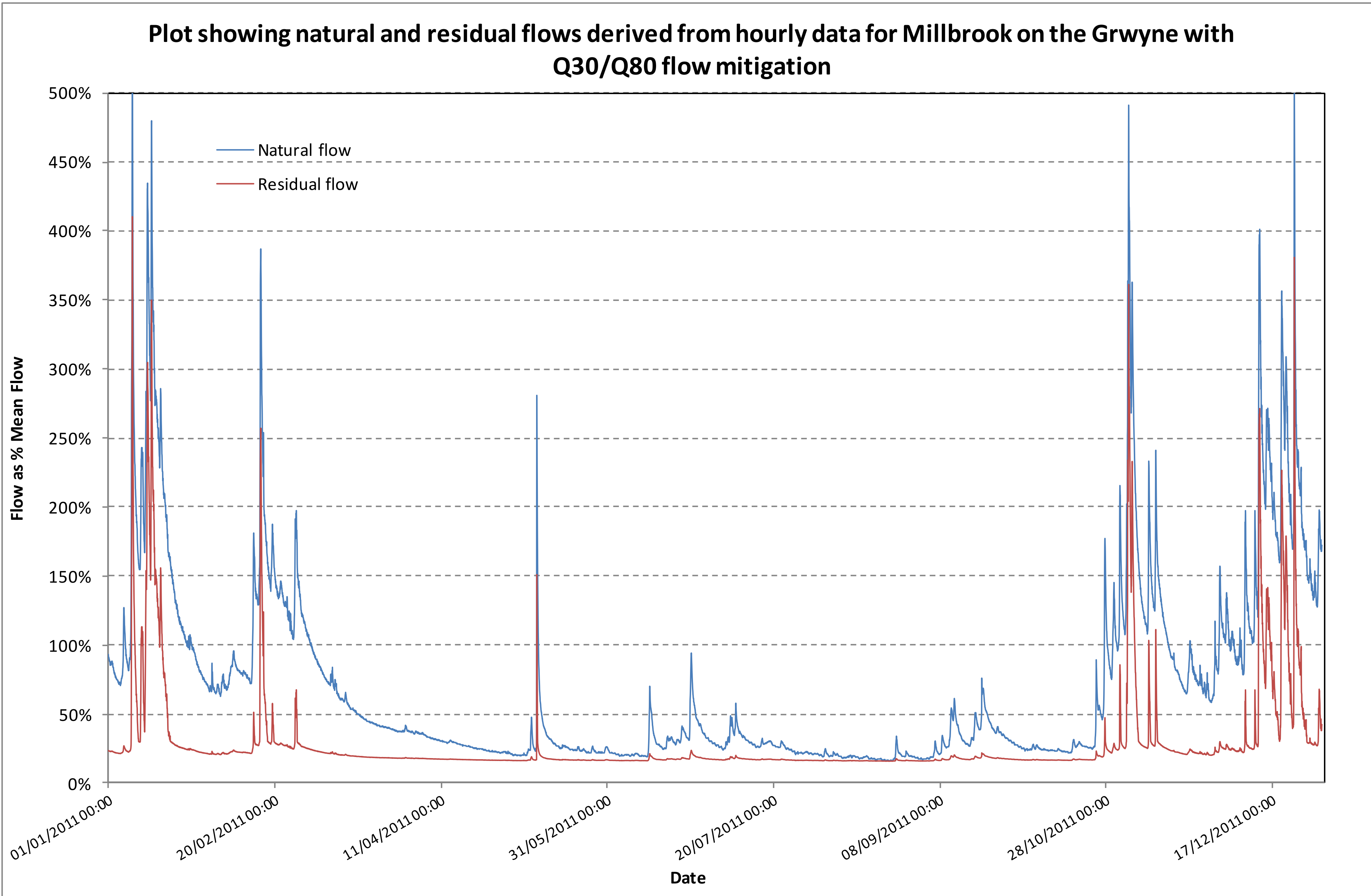


Cyfoeth Naturiol Cymru
Natural Resources Wales



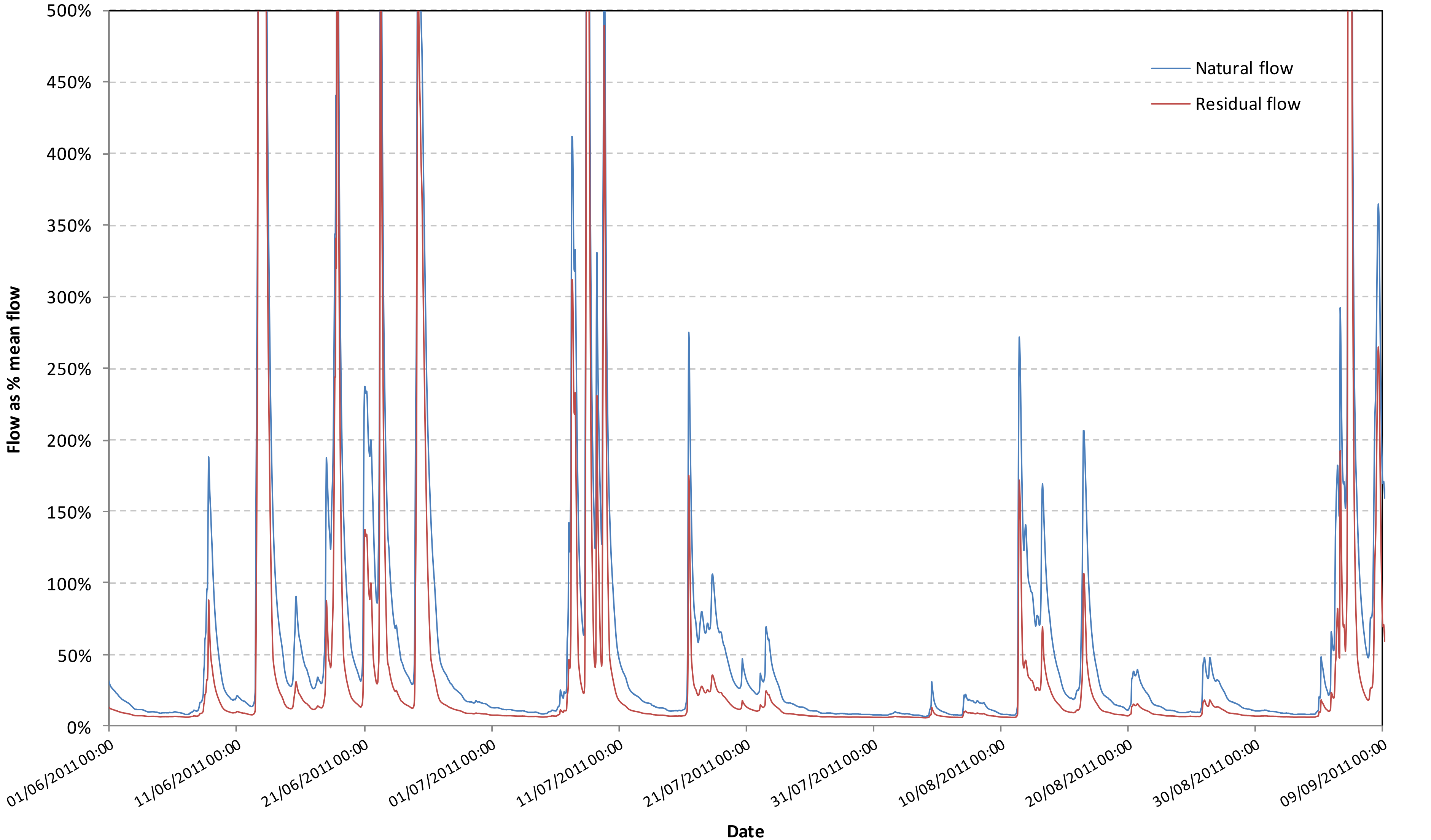


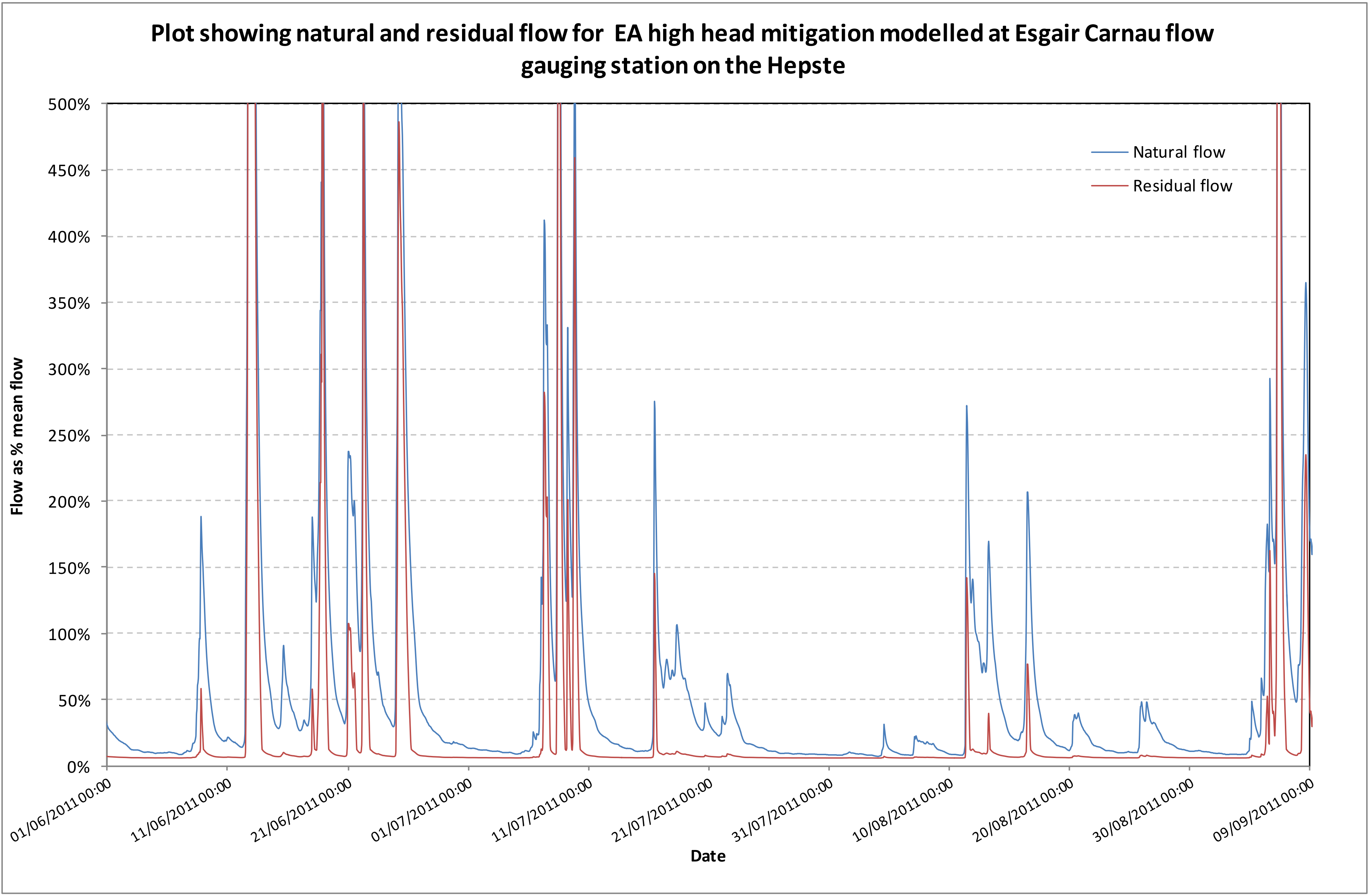
Plot showing natural and residual flows derived from hourly data for Millbrook on the Grwyne with Zone 2 flow mitigation
Natural flow
Residual flow
Flow as % Mean Flow
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
01/01/2011 00:00
20/02/2011 00:00
11/04/2011 00:00
31/05/2011 00:00
20/07/2011 00:00
08/09/2011 00:00
28/10/2011 00:00
17/12/2011 00:00
Date



Plot showing natural and residual flows derived from hourly data for Millbrook on the Grwyne with Q30/Q80 flow mitigation
Natural flow
Residual flow
Flow as % Mean Flow
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
01/01/2011 00:00
20/02/2011 00:00
11/04/2011 00:00
31/05/2011 00:00
20/07/2011 00:00
08/09/2011 00:00
28/10/2011 00:00
17/12/2011 00:00
Date

# Plot showing natural and residual flow for Zone 3 mitigation modelled at Esgair Carnau flow gauging station on the Hepste





Plot showing natural and residual flow for EA high head mitigation modelled at Esgair Carnau flow gauging station on the Hepste
Natural flow
Residual flow
Flow as % mean flow
500%
450%
400%
350%
300%
250%
200%
150%
100%
50%
0%
01/06/2011 00:00
11/06/2011 00:00
21/06/2011 00:00
01/07/2011 00:00
11/07/2011 00:00
21/07/2011 00:00
31/07/2011 00:00
10/08/2011 00:00
20/08/2011 00:00
30/08/2011 00:00
09/09/2011 00:00
Date

# Management Zone definition (2 & 3) and movement between zones

To determine Zone for **indicative mitigation** use criteria of **depleted reach gradient only**

In considering movement **between Zones** take account of a **combination** of the following:

- Depleted reach gradient
- Hydrological regime
- Spatial position in catchment
- Catchment characteristics upstream of abstraction
- Contributing inflows

# Geomorphological siting & design

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WFD - New impoundments in lower catchment streams and rivers are unlikely to be licensed

For smaller impoundments with limited spatial impact -

Sensitive siting to:

- reduce backwater effect
- reduce sediment accumulation
- increase sediment passage
- ensure long term structural stability
- Avoid impacts of structure decommissioning/failure
- have no increase in flood risk

Minimise size of impoundment or preferably no impoundment

# Sediment passage

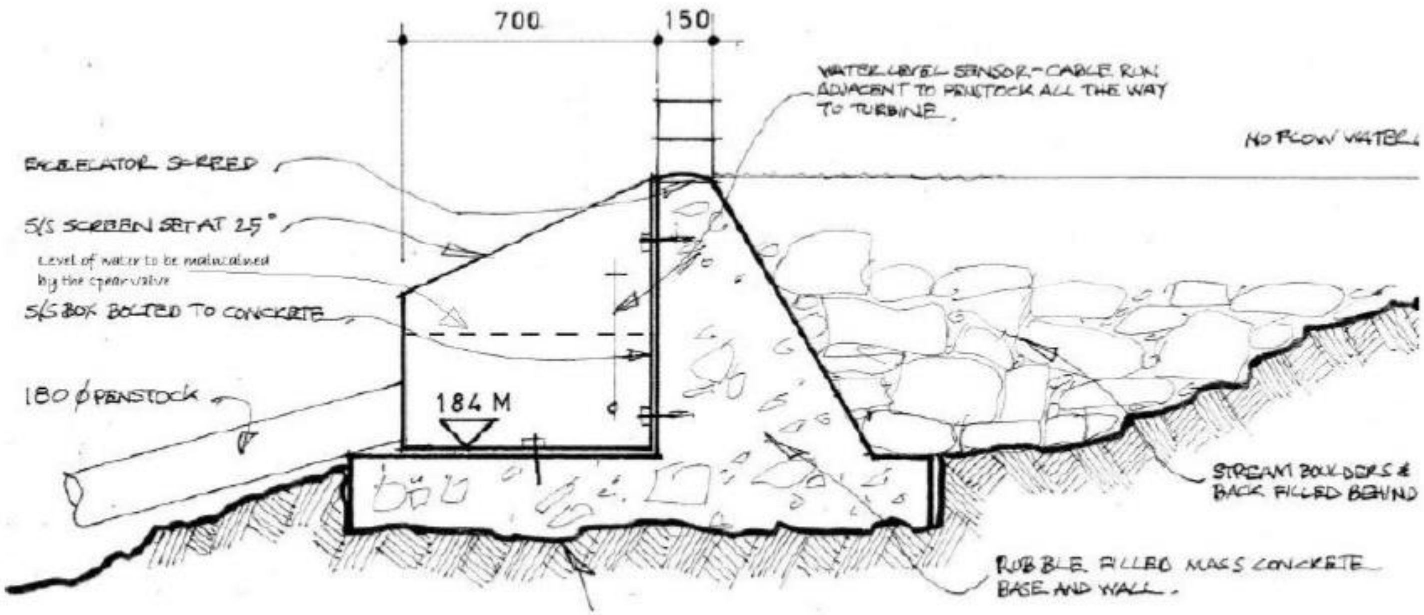


Figure 5-5: Typical Coander abstraction

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## Moorland

Moorlands are upland, low gradient areas, often with nutrient poor and water-logged soils. Siting an intake in an area of moorland:

- Means in channel structures will have a significant impact on channel morphology due the low gradient.
- Increases the likelihood of channel erosion and maintenance issues as the bank material comprises unconsolidated water-logged soil.

## Step-pool

Step features provide a naturally occurring impoundment. Siting an intake at the impounded reach upstream of the step:

- Reduces the potential for morphological change.
- Reduces the likelihood of maintenance (as the channel is already adjusted to the existing sediment regime).

## Active river reach

An active river reach will move across the floodplain. Siting a structure in an active section or on a bend:

- Increases the risk that the structure will be outflanked or undermined.
- Increases the need for maintenance required to address issues with erosion/deposition.

## Waterfall

A waterfall represents flow falling from height at a vertical or near vertical gradient. Siting an intake at a waterfall:

- Prevents flow from being impounded upstream by utilising the steep drop of a waterfall
- Minimises the risk of channel change and the need for river training works (e.g. gabion baskets).

## Tributary

Tributaries can act to replenish a flow depleted channel, therefore:

- Intakes should be built upstream of a tributary confluence.
- Intakes should not be built immediately downstream of a confluence. This can result in the deposition of tributary sediments and result in a requirement for increased maintenance.

## Stable river reach

A stable river reach has adjusted to the sediment regime; while some erosion and deposition takes place the overall channel dimensions should remain the same. Siting a structure in a stable channel:

- Reduces the risk that the structure will be outflanked or undermined.
- Reduces the risk of failure and/or ongoing maintenance.

# Screening

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- Screen design & orientation
- Escape velocities
- Bywash
- Aperture – 3mm to 10 mm
- Type – bar, coanda, perforated plate, belt
- Cleaning
- Fish ‘friendly’ turbines

# Key points to consider for new proposals

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- Where in the catchment is it located?
- Is it on an existing structure?
- Does it create a depleted reach?
- Is it within or likely to affect a designated site or protected species?
- Are there migratory salmonids present?
- What flow standards are likely to be applied?
- Does it have good geomorphological siting & design?