Nutrient management for ecological benefit at Barton Broad and Bosherston Lily Pools, UK:

achievements, costs and long term sustainability issues

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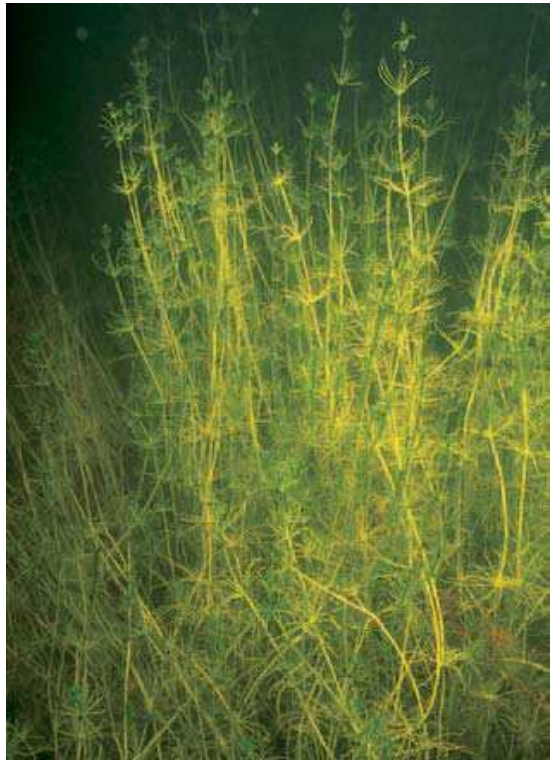
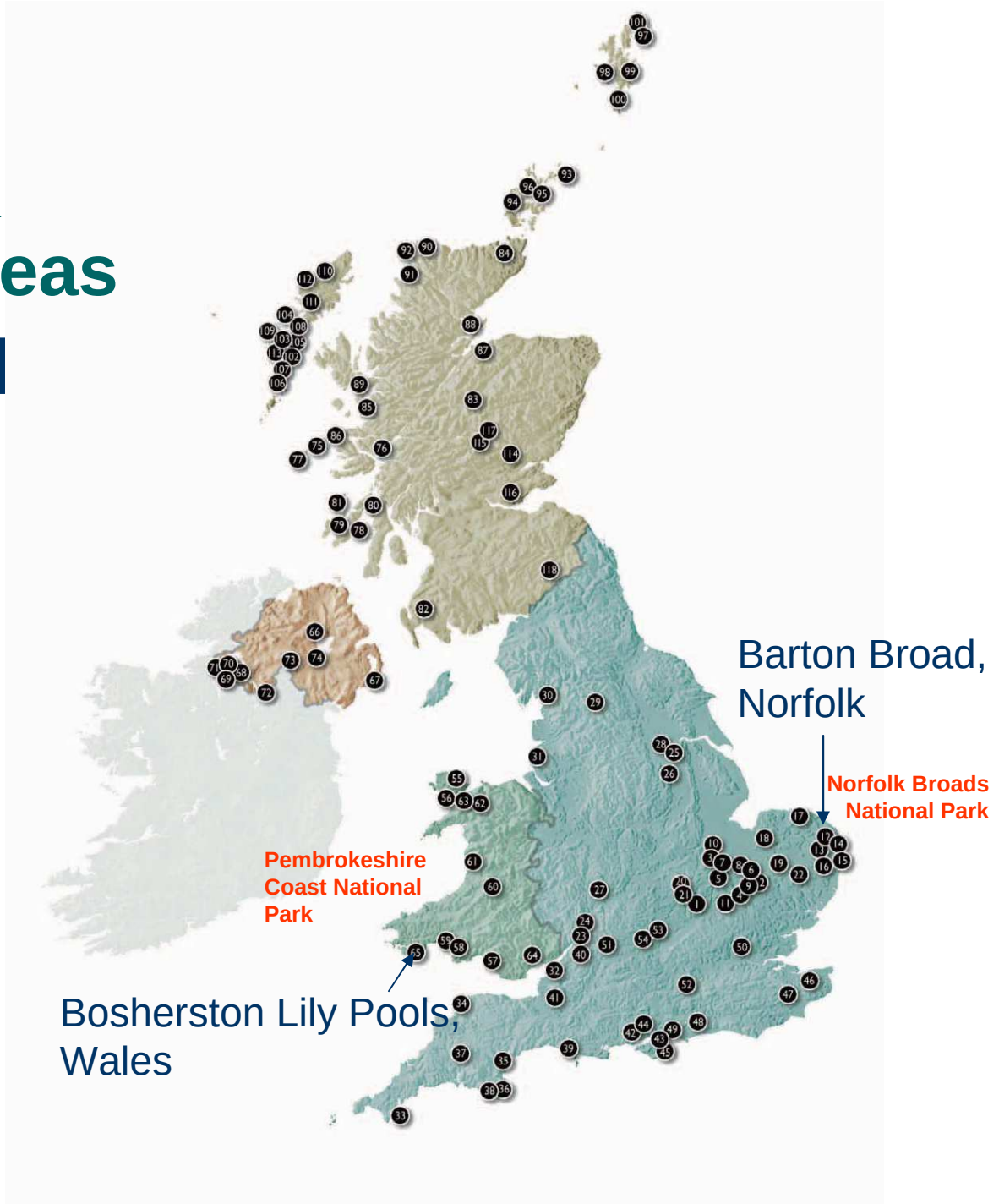
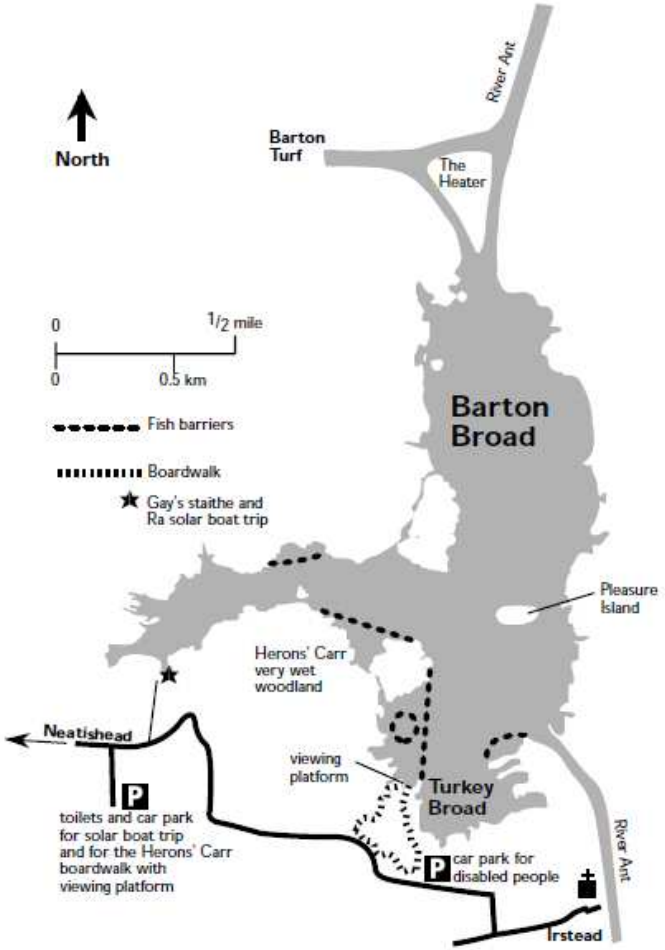
Important UK Stonewort Areas





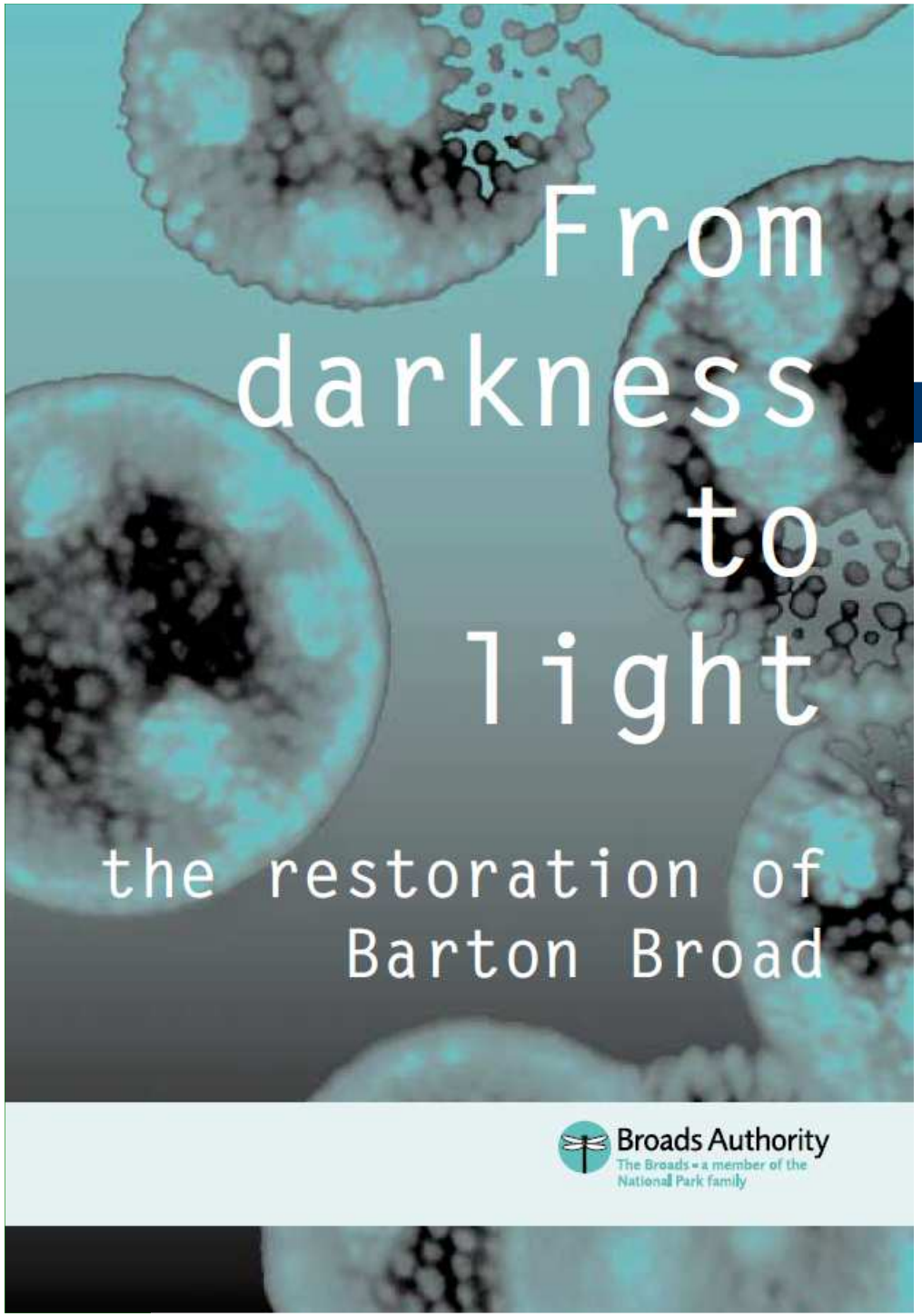
Barton Broad and the Ant Catchment



Barton Broad: the challenge

- Sediment and PP delivery from diffuse catchment sources
- P loading from point sources
- Infilling of the broad, compromising navigation rights
- P enrichment of lake sediments, leading to substantial internal P loading to the water column

- Increased P loading to the water column, sustaining increased algal productivity
- Loss of marginal reed beds through wind stress on reed beds weakened by N enrichment
- Loss of submergent plant community except in sheltered bays, including nationally rare Charophyte species
- Abundant young roach community feeding on equally abundant Daphnia, feeding on abundant algal community
- Green and blue-green algal blooms



Broads Authority
The Broads - a member of the National Park family

The Countryside Agency

DETR

EEDA

Anglian Water

Environment Agency

ukcpi

English Nature

NEWS
Norfolk Environmental Waste Services

Anglian Water Environmental Partnership
a non-profit distributing company

Norfolk Wildlife Trust

M
A Millennium Commission Lottery Project

Project objectives

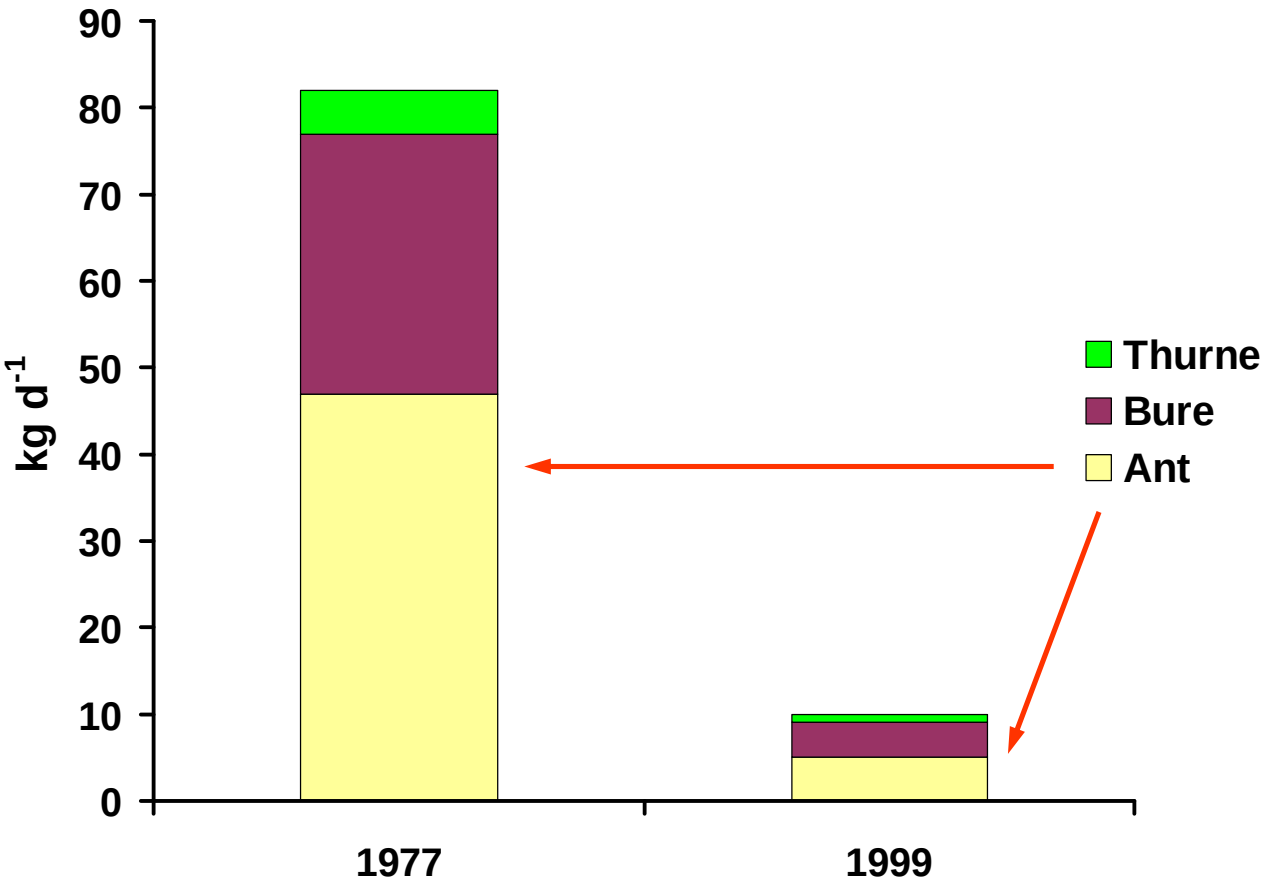
- Improve water quality
- Increase water depth and area of water open for navigation
- Create clear water areas to support plant growth
- Create a better habitat for wildlife in and around the margin of the broad
- Improve accessibility and facilities for visitors by land and on water
- Interpret the science for the benefit of the visitors

Measures adopted 1: Reducing P loading from point sources

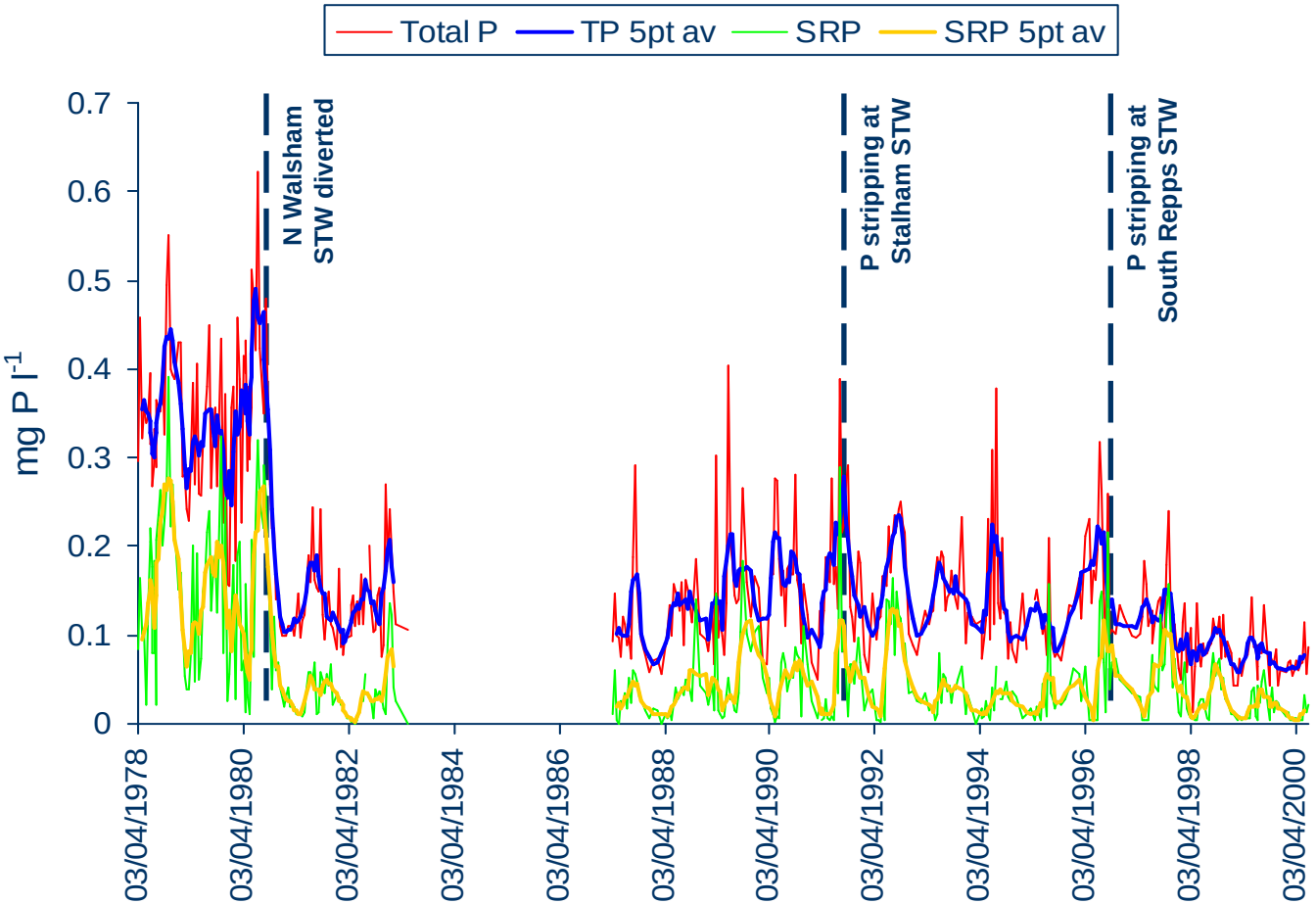
- Diversion of major STW at North Walsham, 1980 to discharge to the North Sea
- Installation of P stripping at remaining medium-sized STWs in the catchment, 1986 to date

Stalham STW *Dynasand* P stripping facility

Reducing point source P loading to Broadland rivers through P stripping

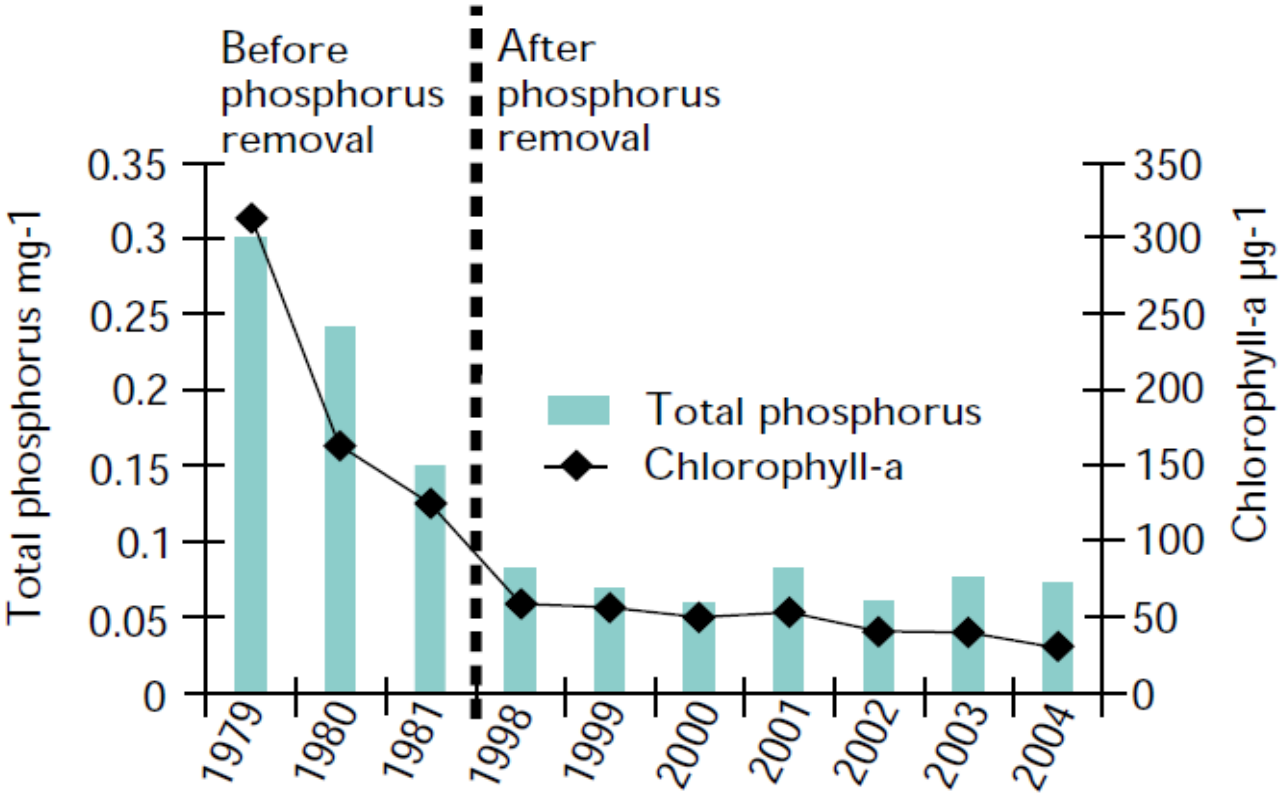


Impact of point source P control measures on P concentrations in the Ant at Hunsett Mill



TP and Chlorophyll α concentrations in the water column following P removal at STWs

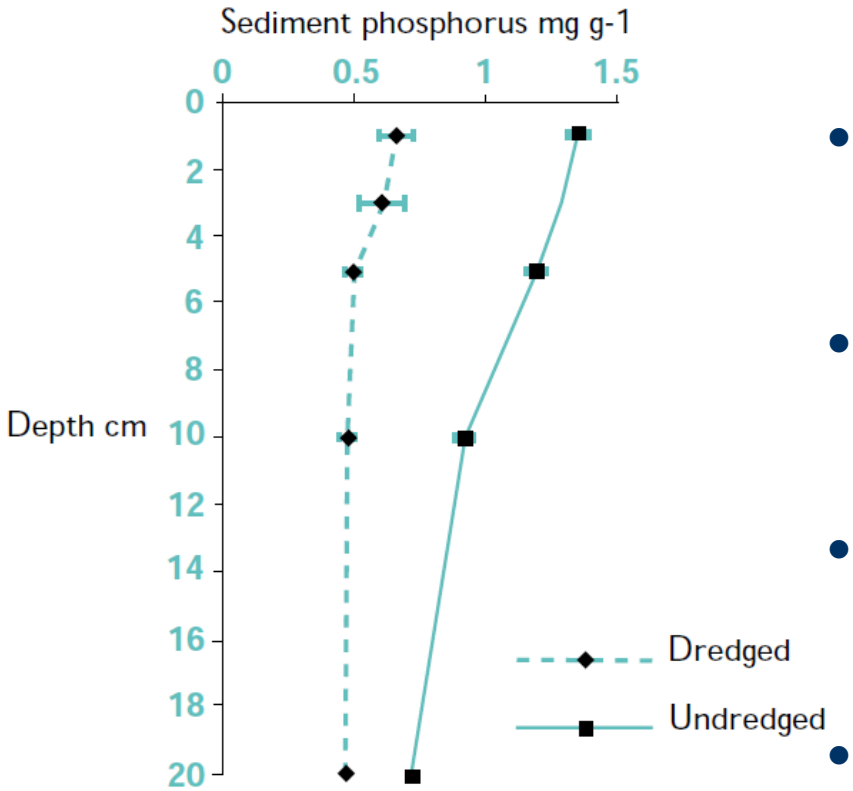
No recovery of the aquatic plant community in open water areas



Measures adopted 2: Sediment dredging

- Dredging took 6 years, 1996-2002
- 305,000 m^3 of sediment were removed
- Dredged sediment was pumped into lagoons on adjacent fields
- Topsoil was used to form bunds between each lagoon
- An estimated 50 tonnes of P were removed, representing 20 years of P loading delivered to the Broad
- After drying each lagoon contained 1m depth of sediment
- Silt was mixed with subsoil, recovered with topsoil and planted with a conditioning crop
- After 1 year, the land was returned to commercial agricultural use

Impact of dredging on P concentrations in sediments



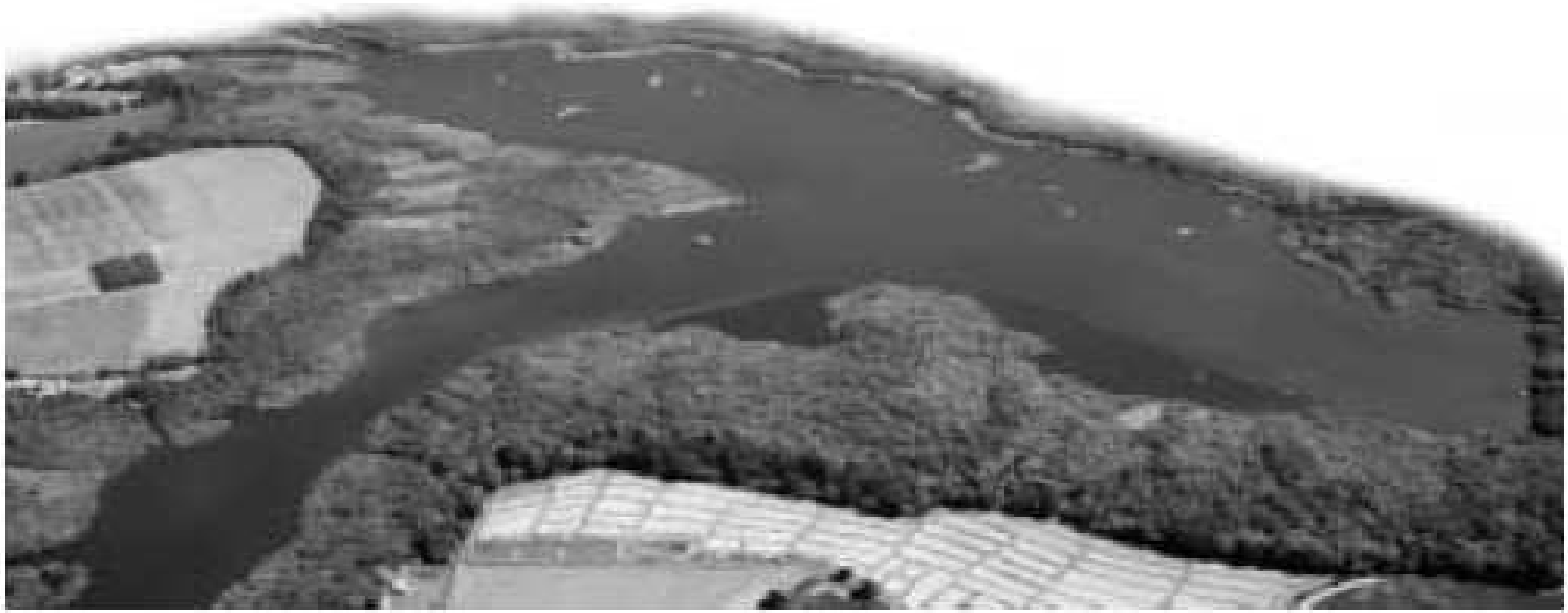
- Sediment P content fell by 50% following dredging
- P concentrations at 3-20 cm depth in the sediment remained 50% lower than in undredged sediments for 5 years
- P concentrations in surface sediments at 1-3 cm depth rapidly increased to following dredging
- Post dredging, P concentrations in surface sediments are comparable with those in undredged sediments,
- P release to the water column has reduced by 60%, post-dredging

Long term impact

- The lagoons were located on agricultural fields adjacent to Barton Broad
- Water draining from the dredged sediments ran back into the broad, reducing costs

- Dry sediment was ploughed back into the field and used to support agricultural production
- Inevitably, P will migrate from the lagoon back to the broad

Aerial view of Barton Broad in relation to the sediment lagoons



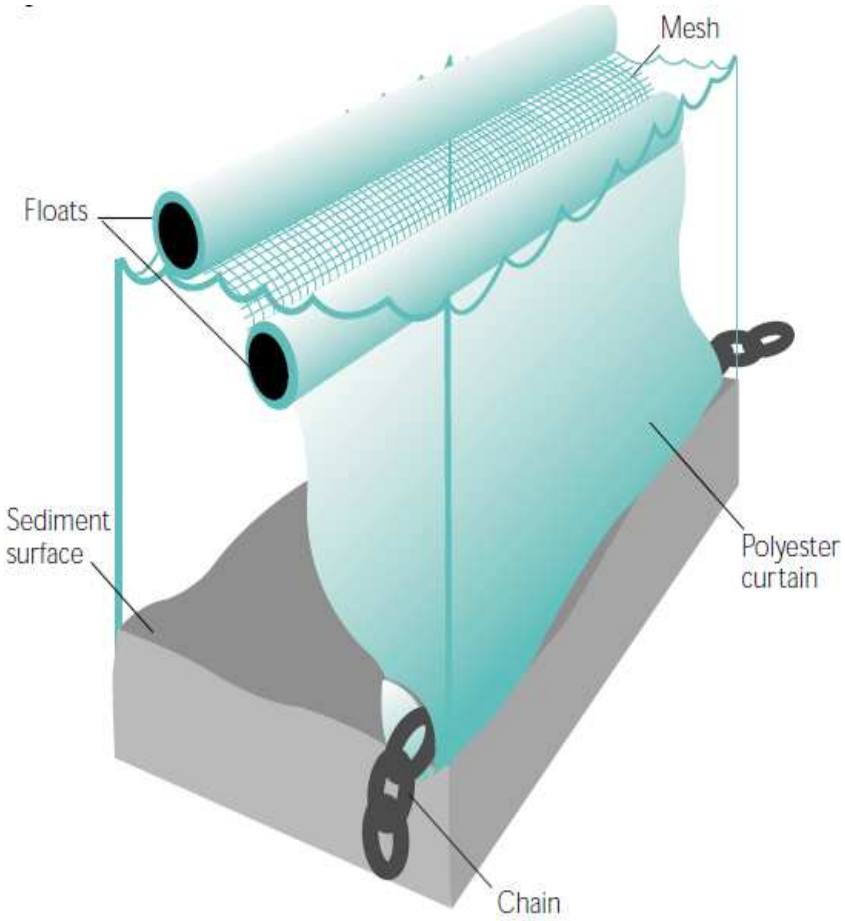
Measures adopted 3: Biomanipulation

Plant exclosures

Electrofishing to remove planktivorous fish (primarily young roach)

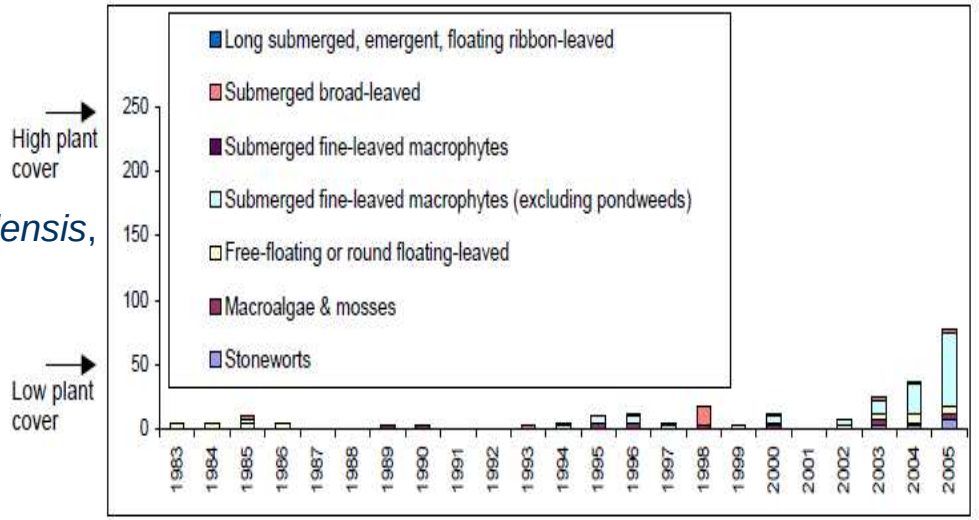
Biomanipulation through fish removal

- Navigation rights prohibited physical isolation of Barton Broad
- Fish were therefore removed from the broad using fish curtains to isolate marginal bays
- Tidal fluctuations in Barton Broad meant that additional costs were incurred in designing a flexible barrier structure
- Water was able to transfer over the top of the barrier.
- Fish were then removed from the exclosures through electrofishing
- In the open water areas outside the exclosures, population density of young roach remains high at 4000-7000 fish per hectare



Impact on biomanipulation on Macrophyte cover in Barton Broad

- **Aquatic plants have been monitored at Barton since 1983**
- **Records indicate sparse cover, with no cover in open water areas in the1980s**
- **In 2005, some plant cover has extended to the margins of the open water area dominated by *Naias marina***
- **In the biomanipulated exclosures, a wider range of species has been recorded including:**
  - Important stonewort species: *Chara hispida, Chara vulgaris*, *Chara virgata*, *Chara globularis*
  - Submergent plants associated with eutrophic waters: *Ranunculus circinatus*, *Elodea canadensis*, *Nuphar lutea, Nymphaea alba*, *Ceratophyllum demersum*, *Callitriche spp*., *Potomogeton pusillus*, *Zannichellia palustris*



Impacts of biomanipulation on plankton communities in Barton Broad

Daphnia population has declined 1996-2000

- 1950 - 1970, low abundance of green algae and blue-green algae, with dominance by diatom species
- 1970 – 1980 dominance by blue green algae
- 1980 – 1996 dominance by green algae
- 1996 – 2000 abundance of green and blue green algae reduced by 75% within the exclosure
- 1996 – 2000 Daphnia populations declined in the clear water areas, through (?) more effective fish predation in improved light conditions
- 2005 – to date, blue-green algae again evident in the clear water areas

Impacts of dredging on water depth, TP and Chlorophyll a concentrations and Daphnia abundance in Barton Broad

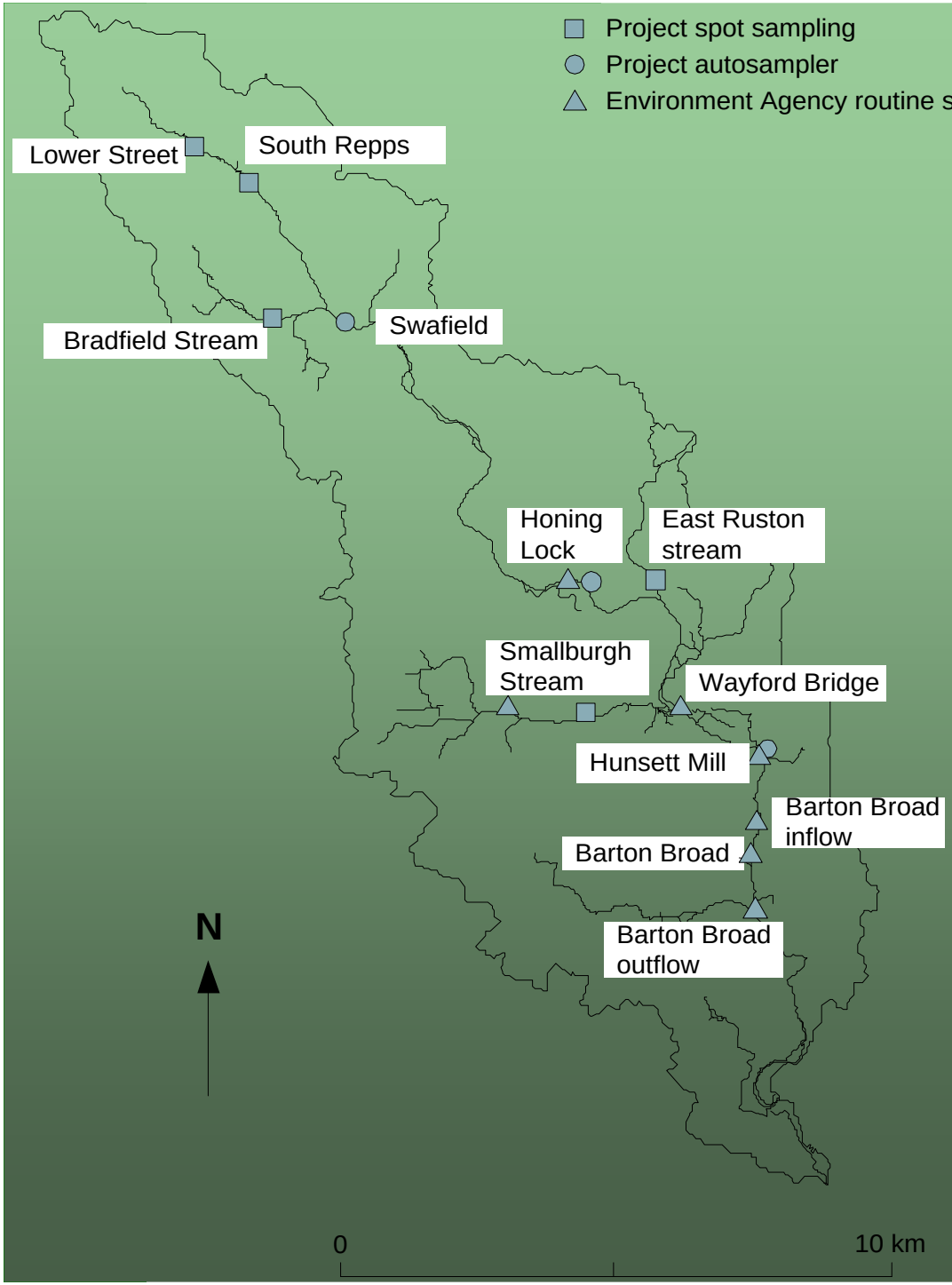
Conditions before and after dredging in Barton Broad (mean ± standard errors).

	1995 pre-dredging	2000 post-dredging Main Broad	2000 post-dredging Exclosures
Water depth	1.2m	1.7m	1.5m
Total Phosphorus mg /1^{-1}(a)	0.121±0.015	0.06±0.005	0.06±0.005
Chlorophyll-a µg/l^{-1}(*a)	70±14	50±8.9	16.4±4.8
Daphnia individuals/l^{-1}(a)	45±16	7±4	91±16

Also includes the impact of post-dredging improvements to P stripping at STWs

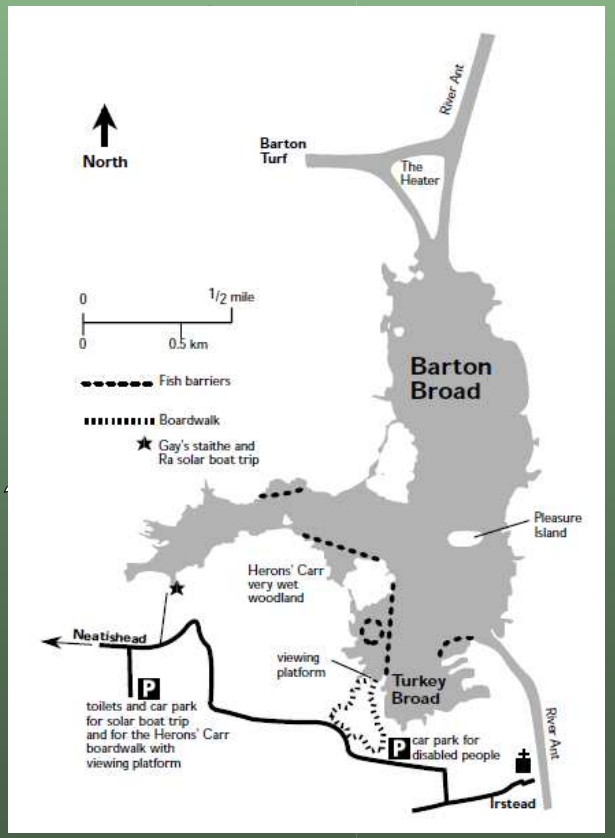
What has it achieved?

- Dredging has increased water depth by up to 0.5m, resulting in an increase in navigable area of 28 ha (35% of the open water area)
- Biomanipulation led to the generation of clear water and increased plant growth within the exclosure areas, but this was a fragile state
- When fish got into the exclosures, algal growth rapidly increased and water clarity was reduced
- There remains near absence of plant growth in the open water areas
- The barriers installed to restrict fish movement also reduced wave action, reducing sediment-resuspension in open water areas
- One unexpected benefit of reduced wave action has been the colonisation of some margins of the open water, outside the exclosure area, by yellow water lily (*Nuphar lutea*)
- Continued fish removal from the exclosures is essential to maintain this fragile ‘recovery’

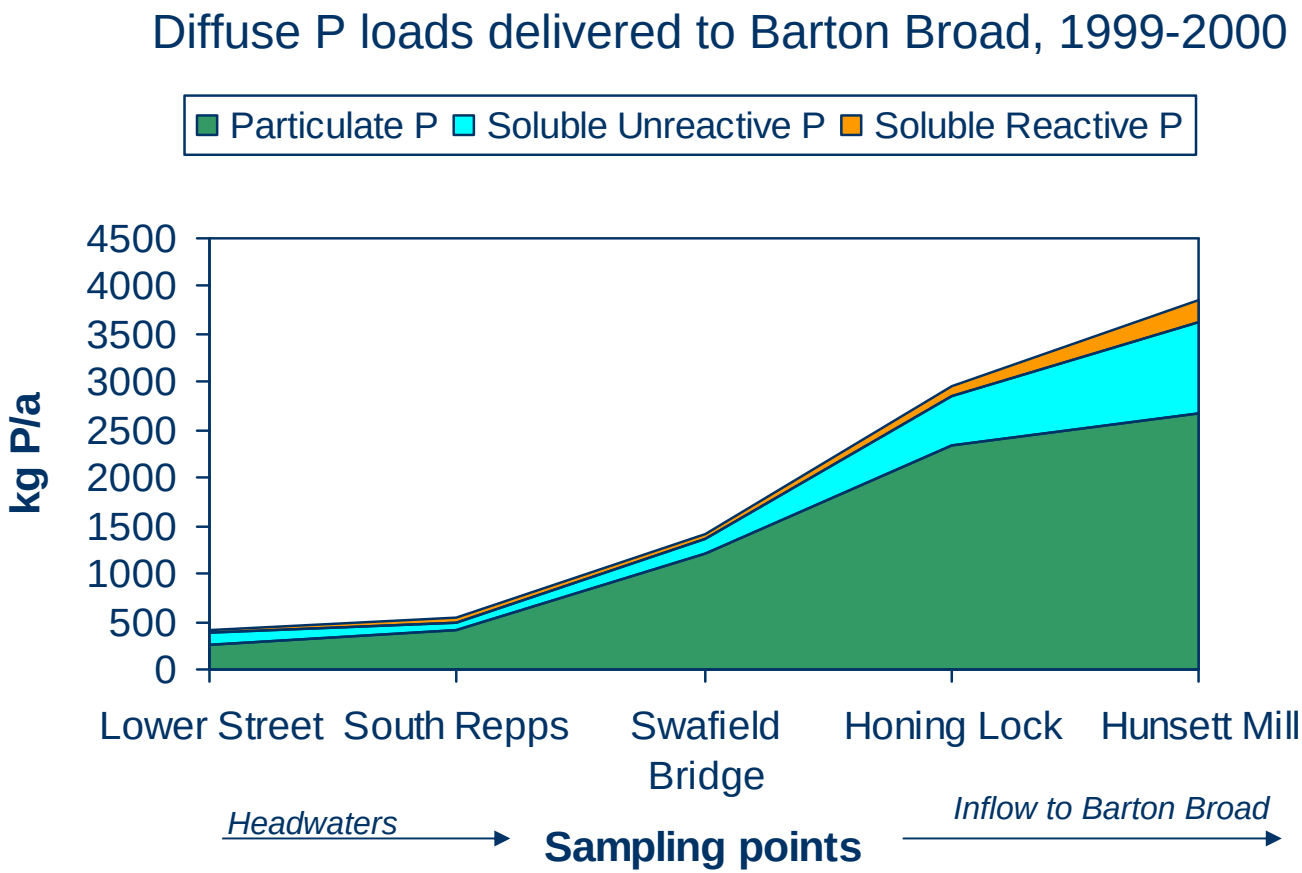


What did it miss?

Diffuse nutrient loading on Barton Broad from the Ant catchment



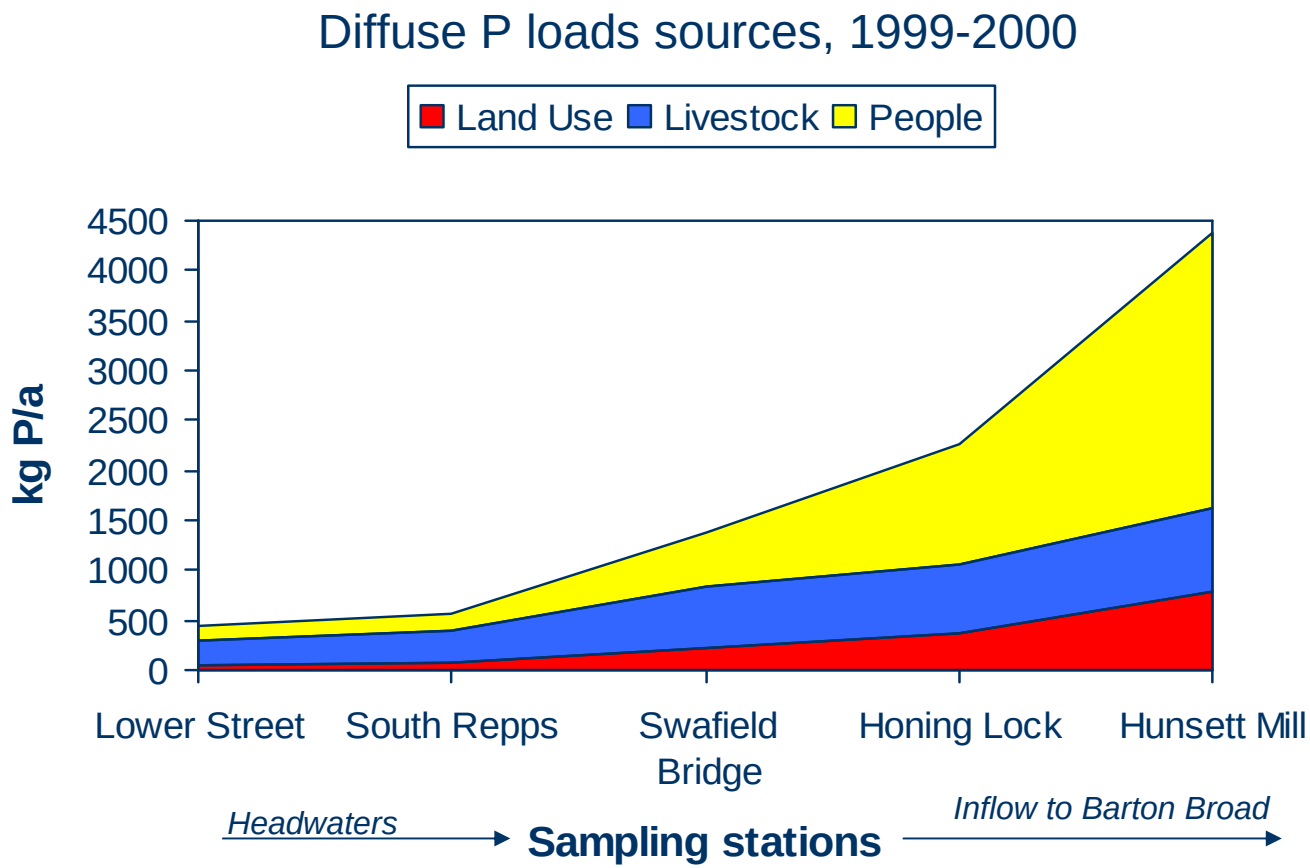
Continued diffuse P loading from the Ant catchment compromises restoration efforts at Barton Broad



Diffuse agricultural sources have yet to be tackled

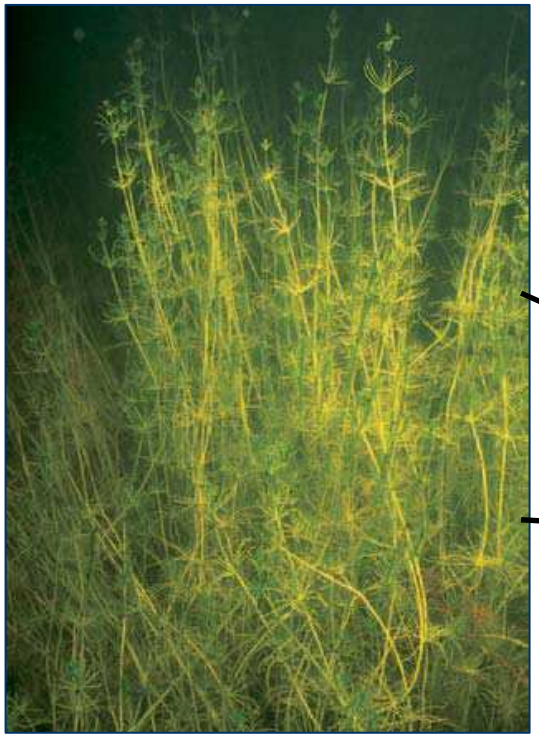
Designation of the Ant catchment as an NVZ, 1 January 2009 may help re-focus efforts

Sources of diffuse P loading delivered to Barton Broad from in the Ant catchment

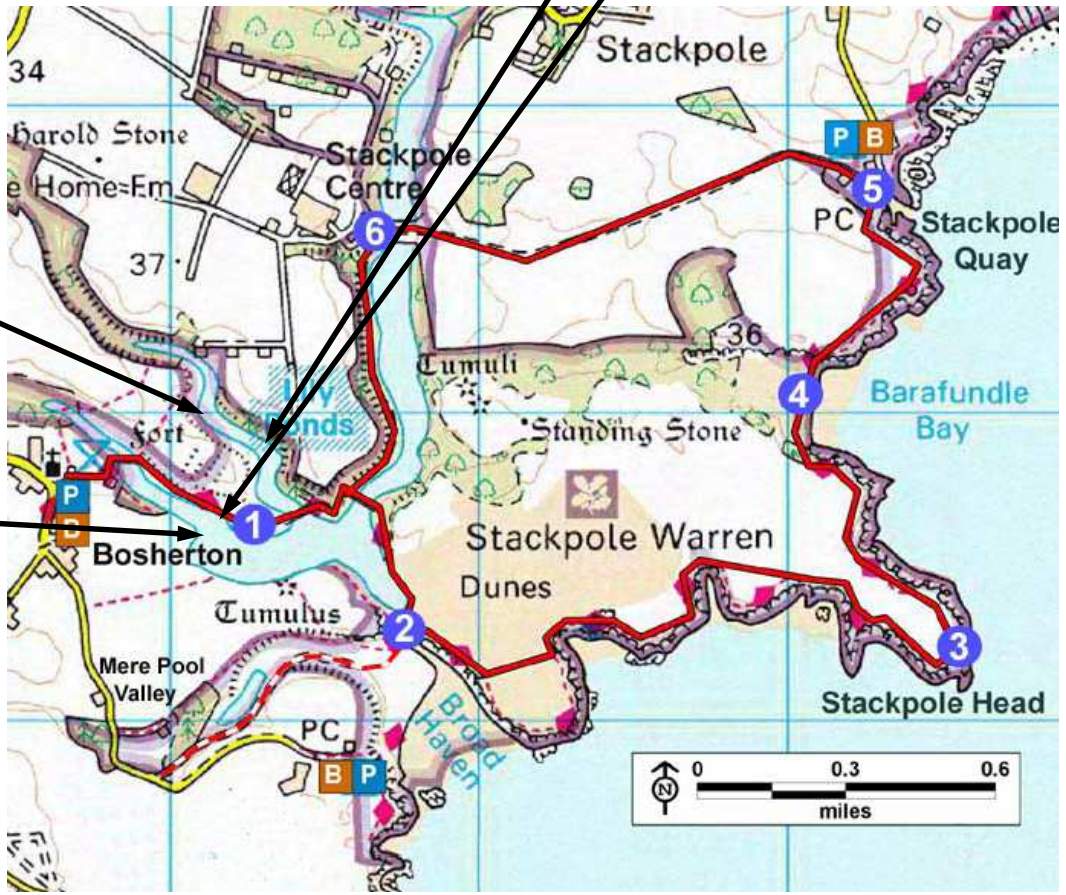


Bosherston Lily Pools, Wales
(SSSI, SPA, SAC and NNR)

Nymphaea alba



Charophyte spp.

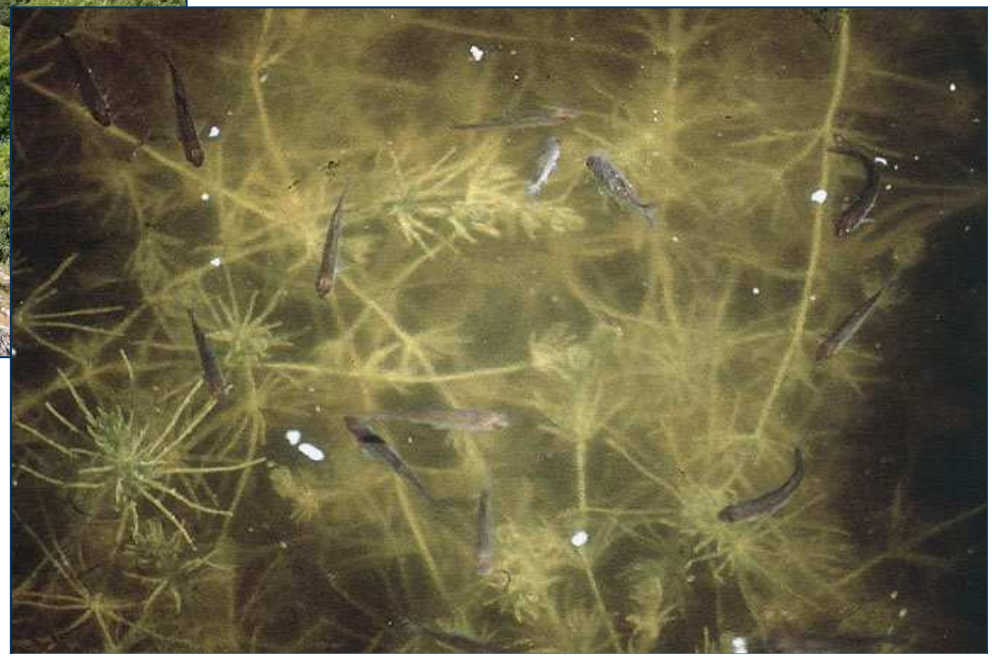


Aquatic plant communities at Bosherston Lily Pools

Nymphaea alba

Charophytes and *Nymphaea alba*, Western Arm

***Chara hispida*, Central Arm**



Indicators of ecosystem stress at Bosherston Lily Pools

Excessive plant growth in the Eastern Arm

Infilling of the Eastern Arm with sediment eroded from the catchment

Filamentous algal mats on emergent vegetation, Upper Western Arm

Cyanobacterial blooms, Eastern Arm

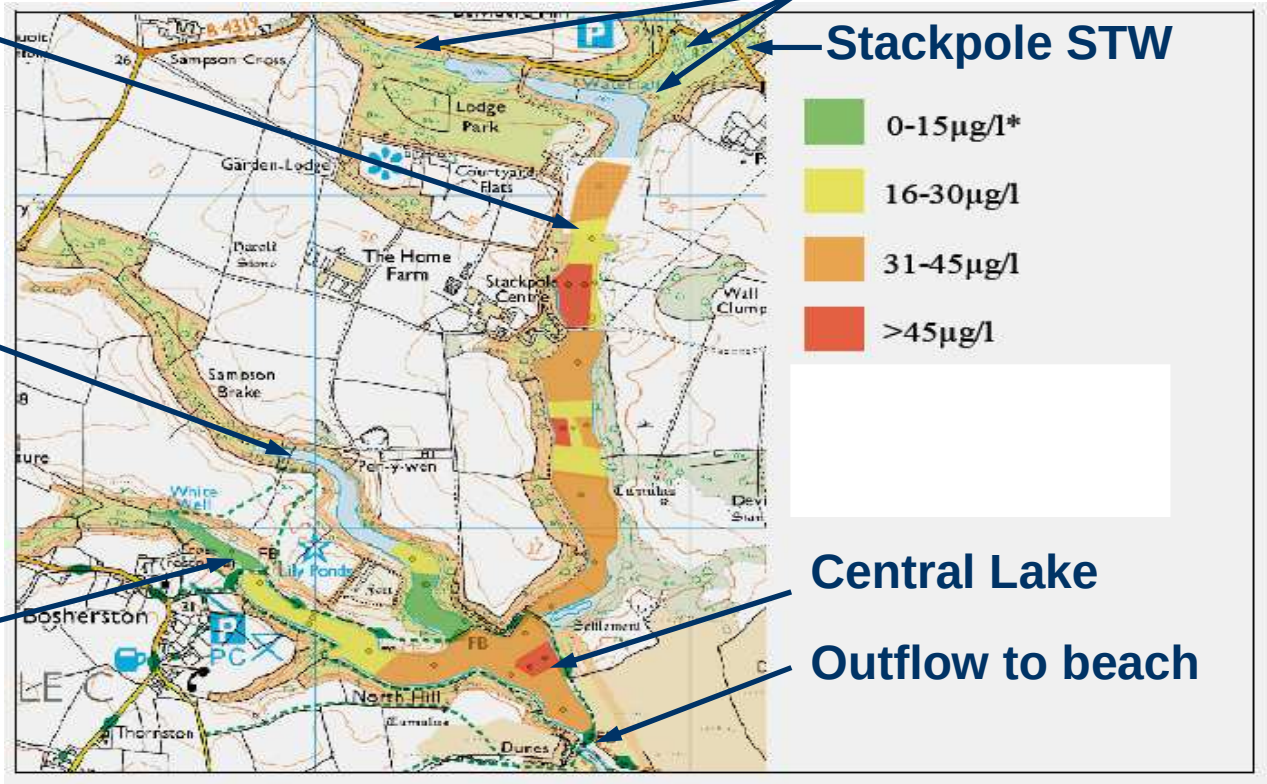
Macrophyte colonisation, Upper Eastern and Western Arms on areas infilled with sediment

Lake Total P concentrations, in Bosherston Lily Pools, Summer 2008

Eastern Arm
- Surface inflows
- Old Red Sandstone
- Intensive dairy and beef cattle farming

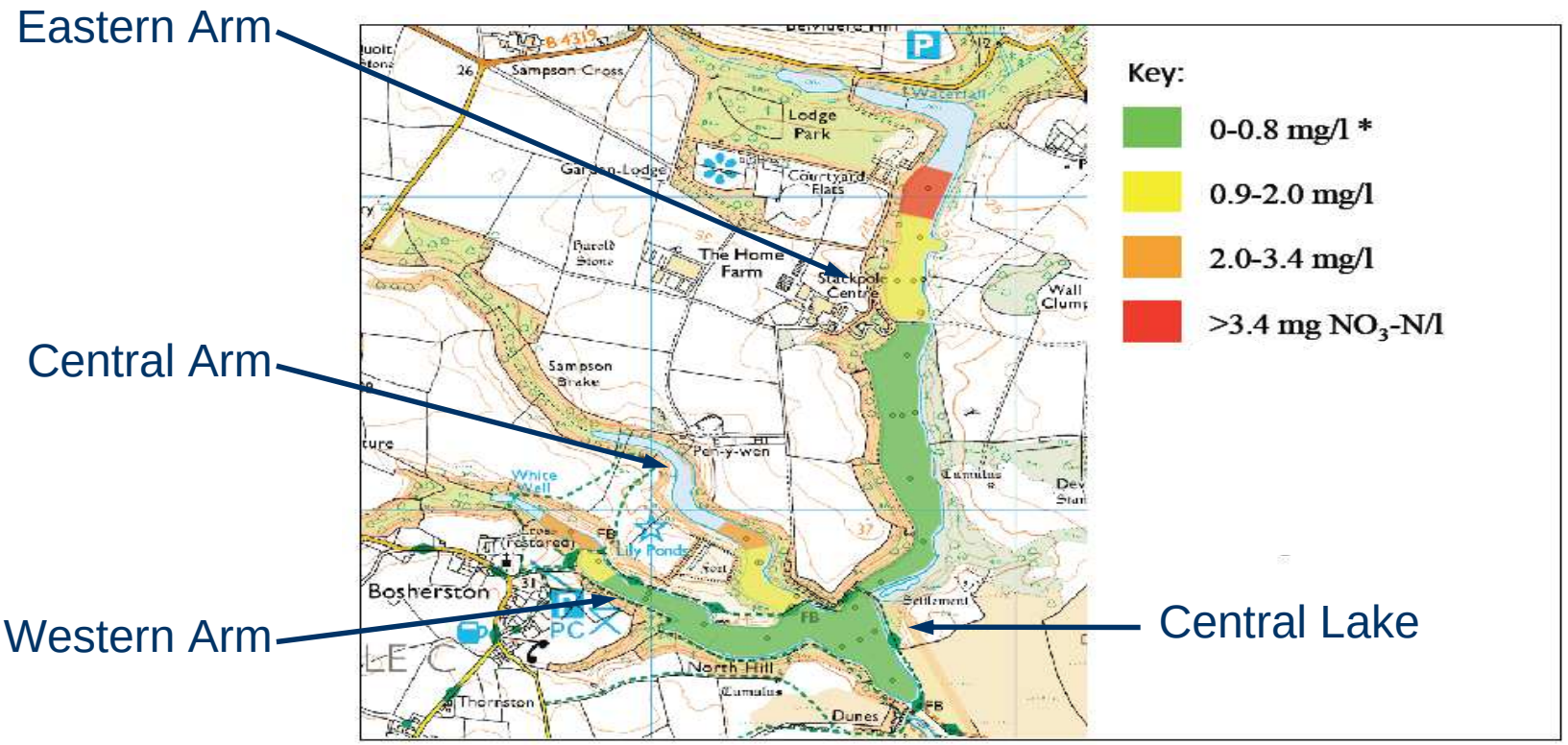
Central Arm
- Spring fed
- Carb. Limestone
- Military Firing Range
- Low intensity grazing
- No fertilisers

Western Arm
- Spring fed
- Carb. Limestone
- Military Firing Range
- Some agriculture
- Septic tanks in village



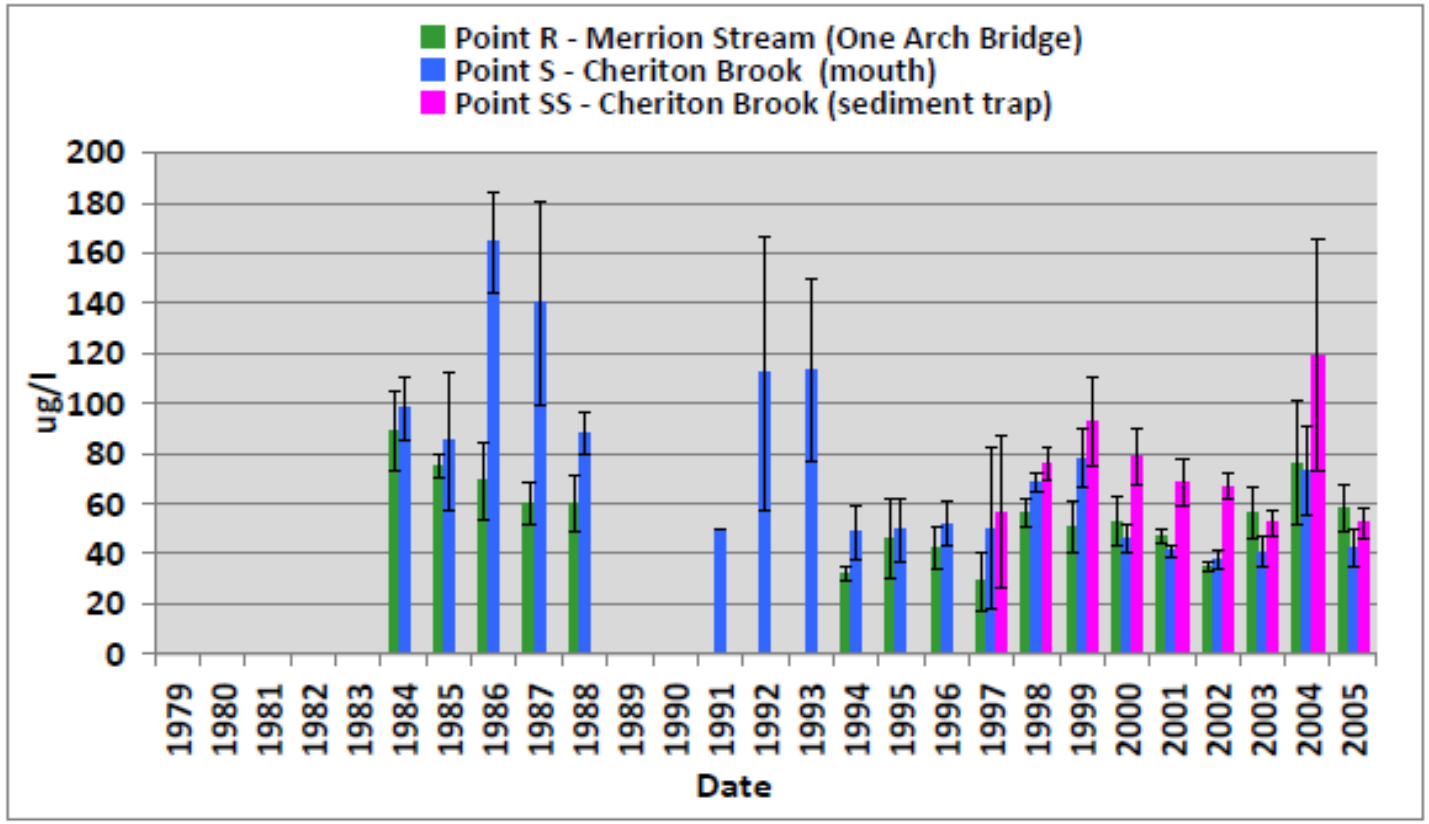
(after Nicieki, 2008)

Lake NO_3-N concentrations, in Bosherston Lily Pools, Summer 2008



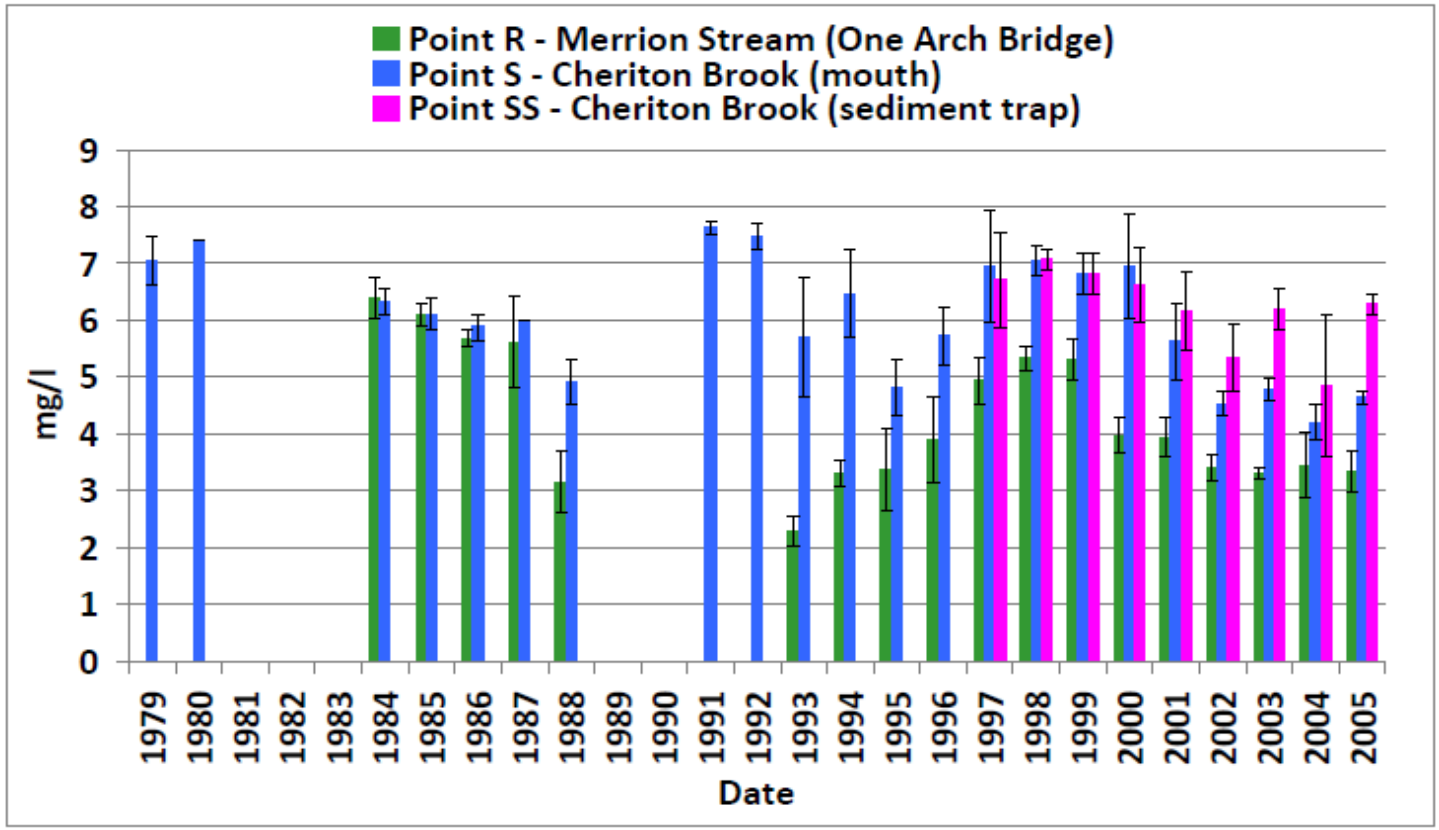
(after Nicieki, 2008)

Mean summer TP concentrations in surface inflows, to the Eastern Arm, Bosherston Lily Pools, 1979-2005



(Data source: Environment Agency, after Nicieki, 2008)

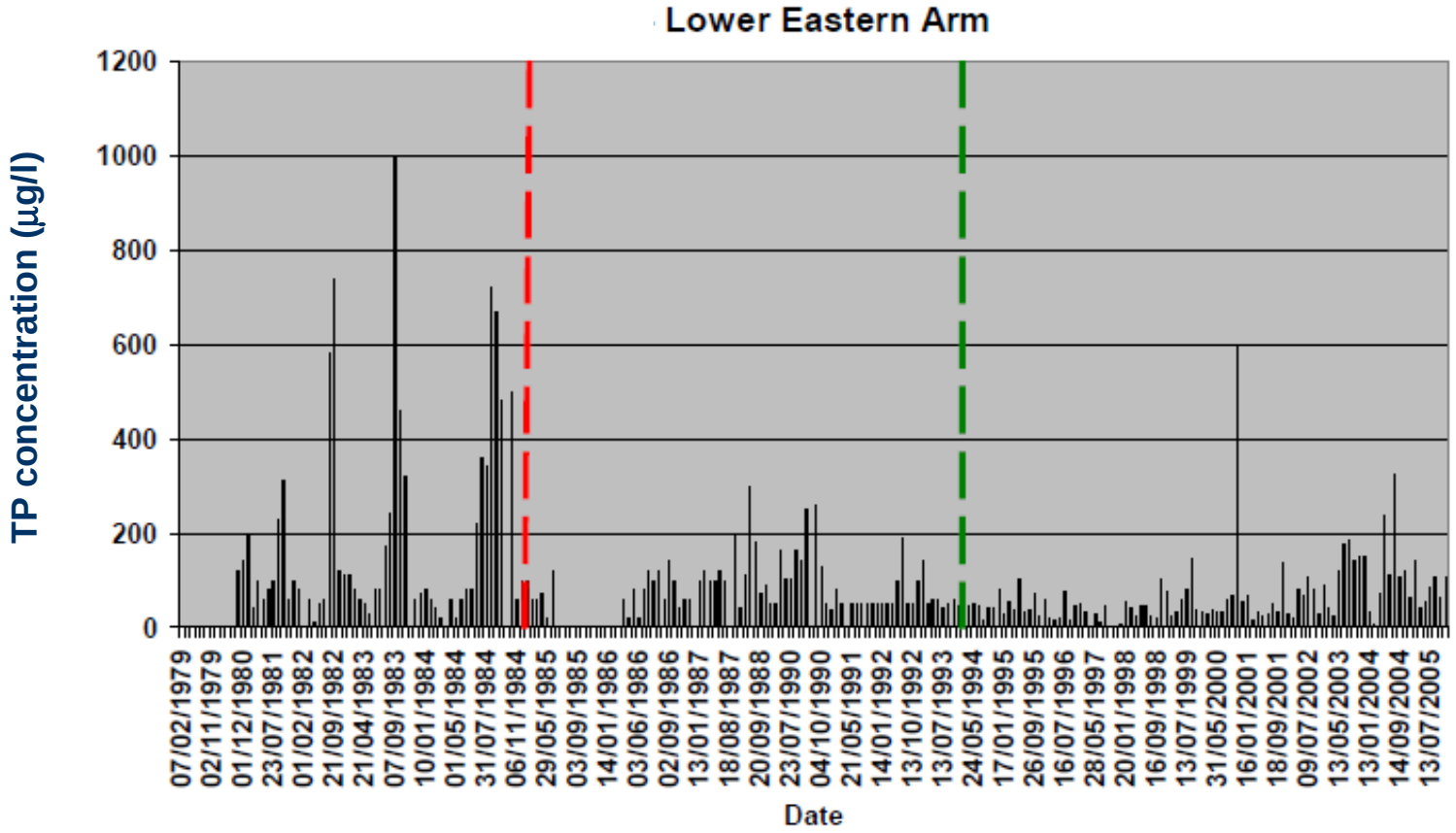
Mean summer NO_3-N concentrations in stream inflows to the Eastern Arm, Bosherston Lily Pools, 1979-2005



(Data source: Environment Agency, after Nicieki, 2008)

Diversion of STW
Change in data protocol

Long term trends in TP concentrations in Bosherston Lily Pools, 1979-2005



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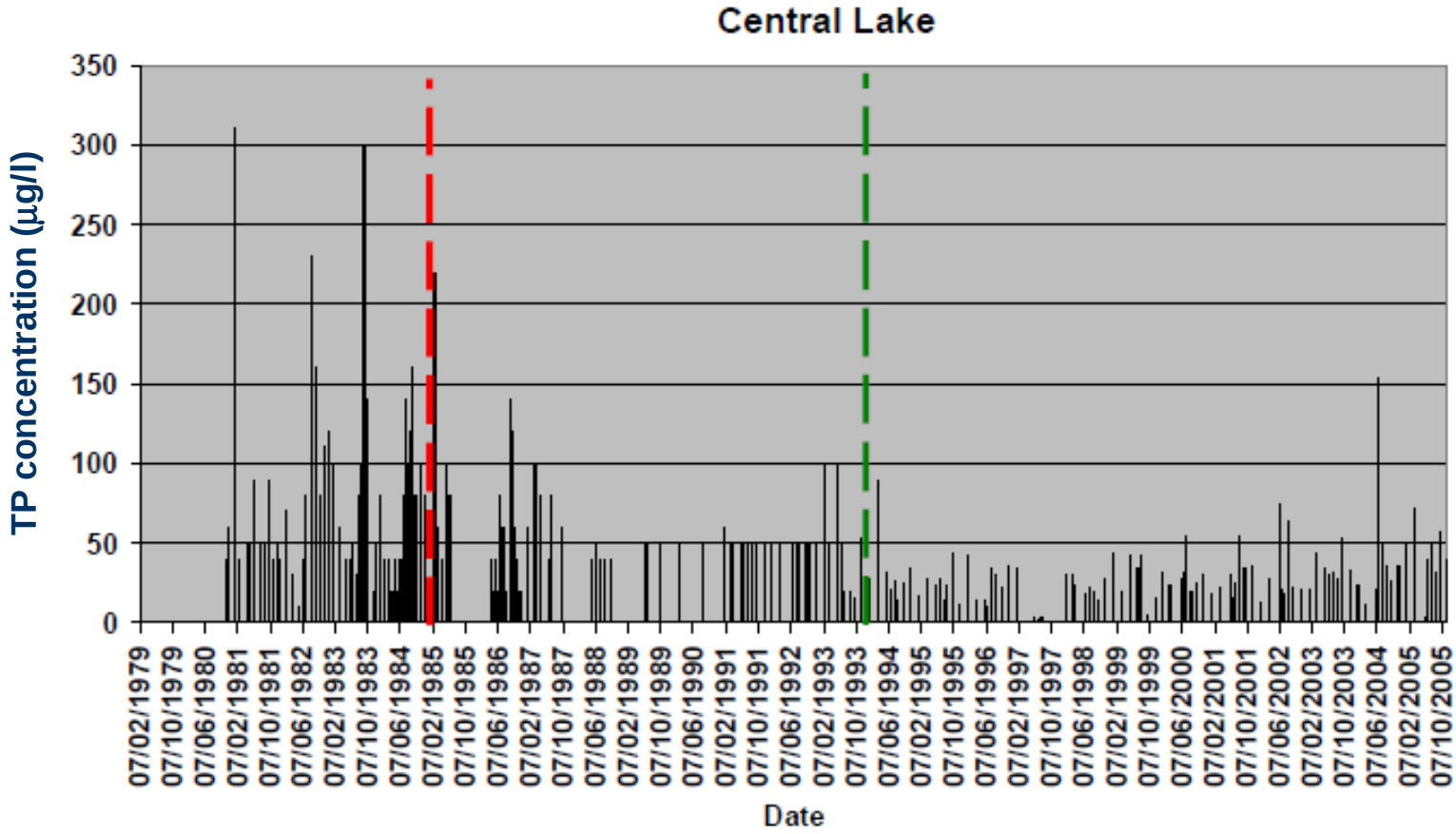

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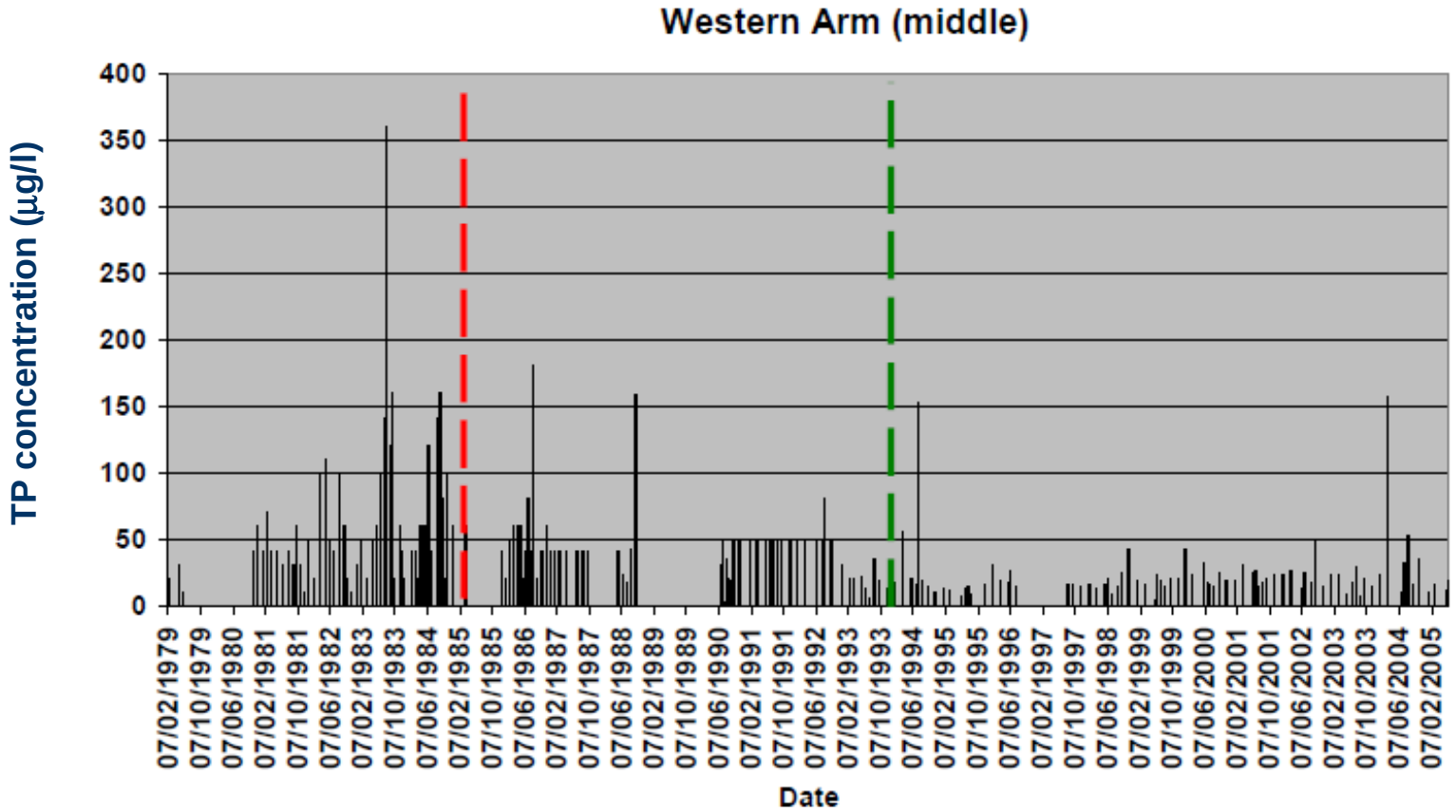

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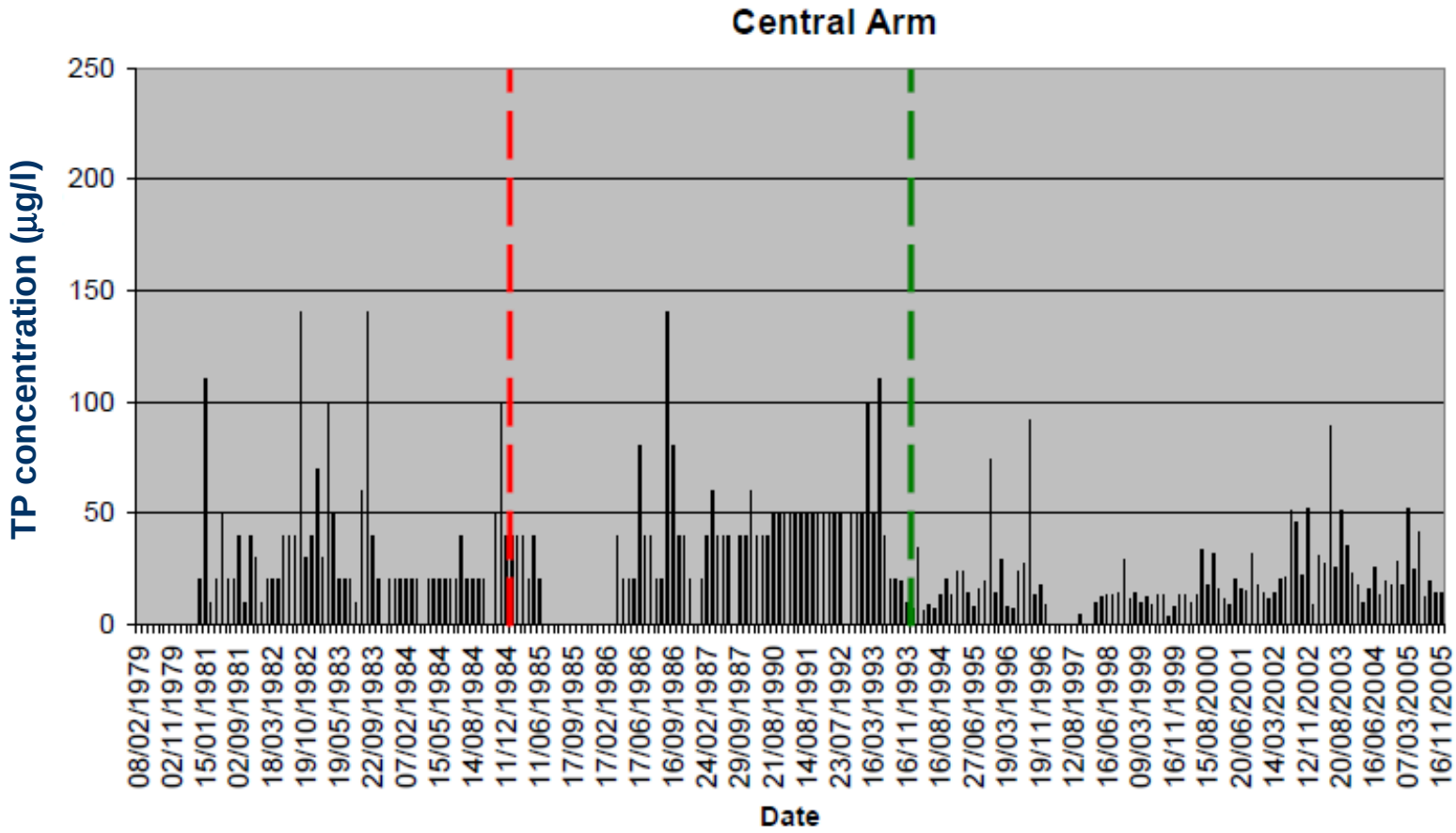
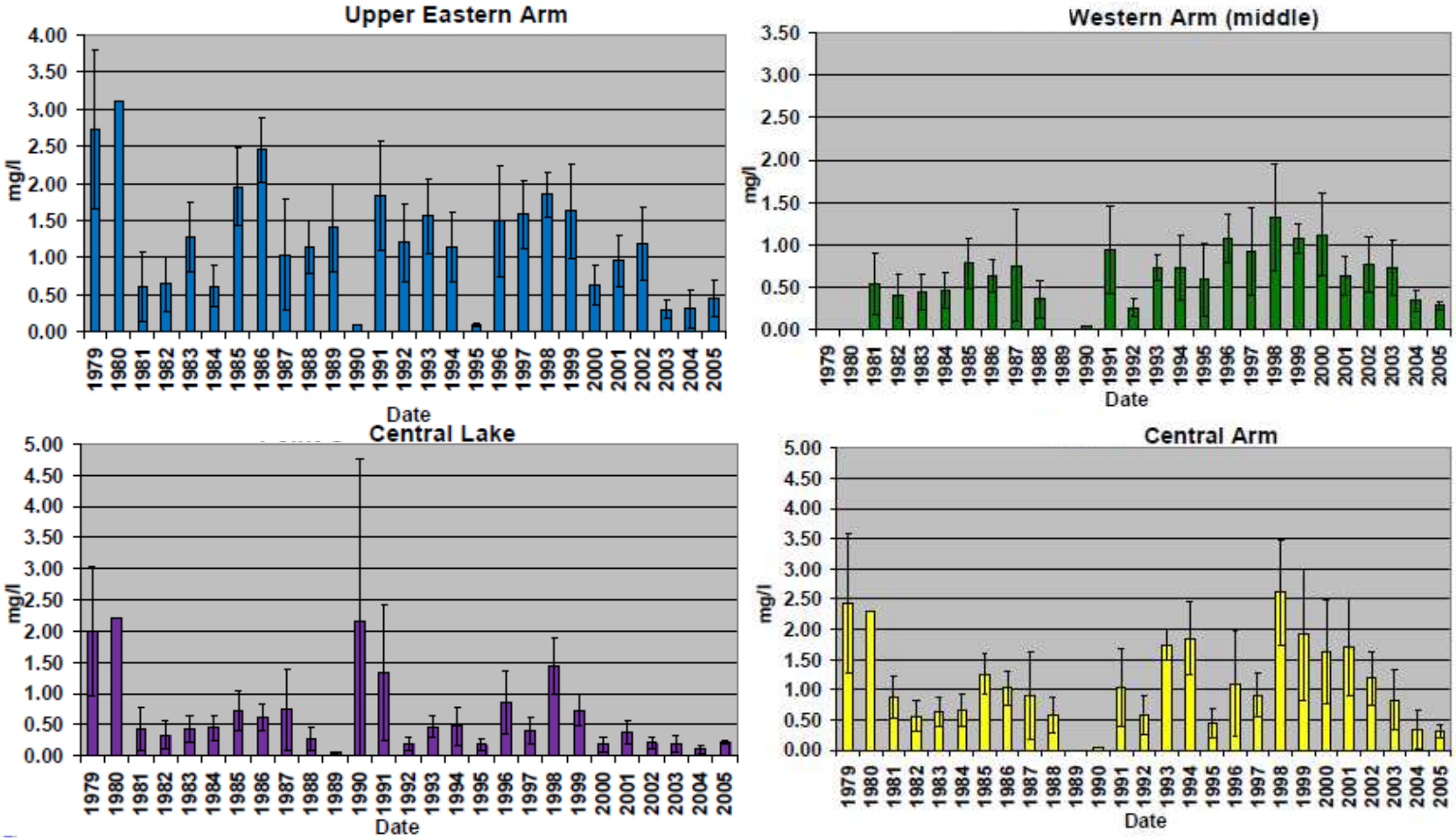


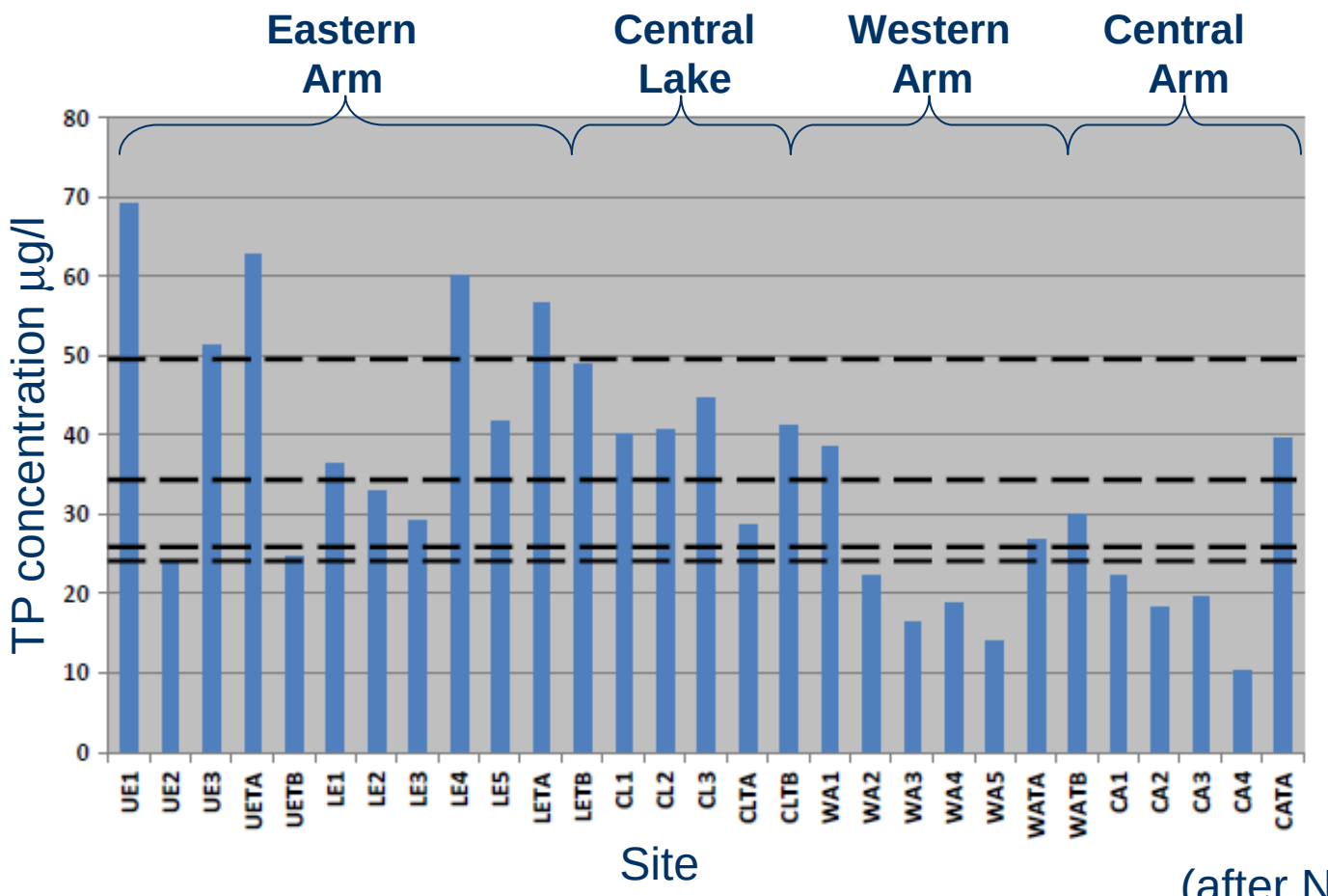
(Data source: Environment Agency, after Nicieki, 2008)

Mean lake NO_3-N concentrations in Bosherston Lily Pools, 1979-2005



(Data source: Environment Agency, after Nicieki, 2008)

Lake TP concentrations in Bosherston Lily Pools, summer 2008, relative to Charophyte sensitivity thresholds



C. globularis

C. hispida

C. virgata

C. vulgaris

(after Nicieki, 2008)

Measures adopted 1: Excavating sedimentation ponds at the top of the Eastern Arm

A total of 15,000 m^3 of sediment was removed

- **Phase 1 excavation has focused on clearing infilled old fish ponds**
- **Phase 2 excavation has created new sedimentation ponds further upstream**
- **Five main pools have been dug since 1993.**
- **Excavation completed 2008, Upper Western Arm**

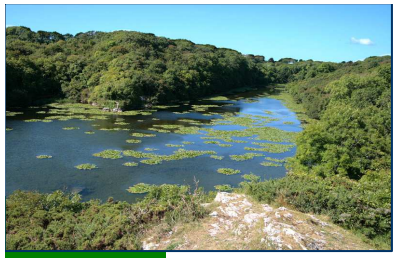
Measures adopted 2: ‘Weed’ harvesting to reduce recycling of nutrients within the plant biomass

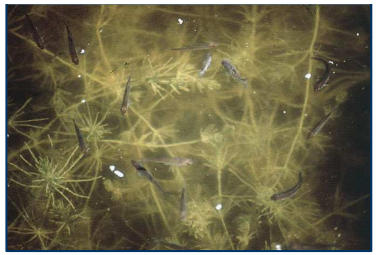
Annual cost of ca. €10,000

- **Vegetation is cut at a depth of 1 metre from a flat-bottomed punt**
- **Cut material is taken on board, then deposited on the lake shore**
- **No provision is made to prevent nutrients released from biodegraded plant material from re-entering the lake**

Measures adopted 3: Diverting nutrient rich water to the sea

- Diversion of effluent from Stackpole STW to discharge to the sea, 1984
- Diversion of nutrient rich from the Eastern Arm, under the Central Lake to discharge to the Atlantic at Broad Haven Beach
- Undertaken to protect relatively healthy Charophyte community in the Central Arm, lying to the North of the Central Lake
- Flows of nutrient rich water are diverted through a 56 cm diameter polyethylene pipe, sunk on to the bed of the Central Lake from a sluice at the end of the Eastern Arm to a sluice at the outflow onto the beach
- The pipe is weighted with concrete sleeves and is only visible at low flows
- Water is diverted through the pipe during the late spring and summer when nutrient loadings are greatest due to low lake levels and internal P loading

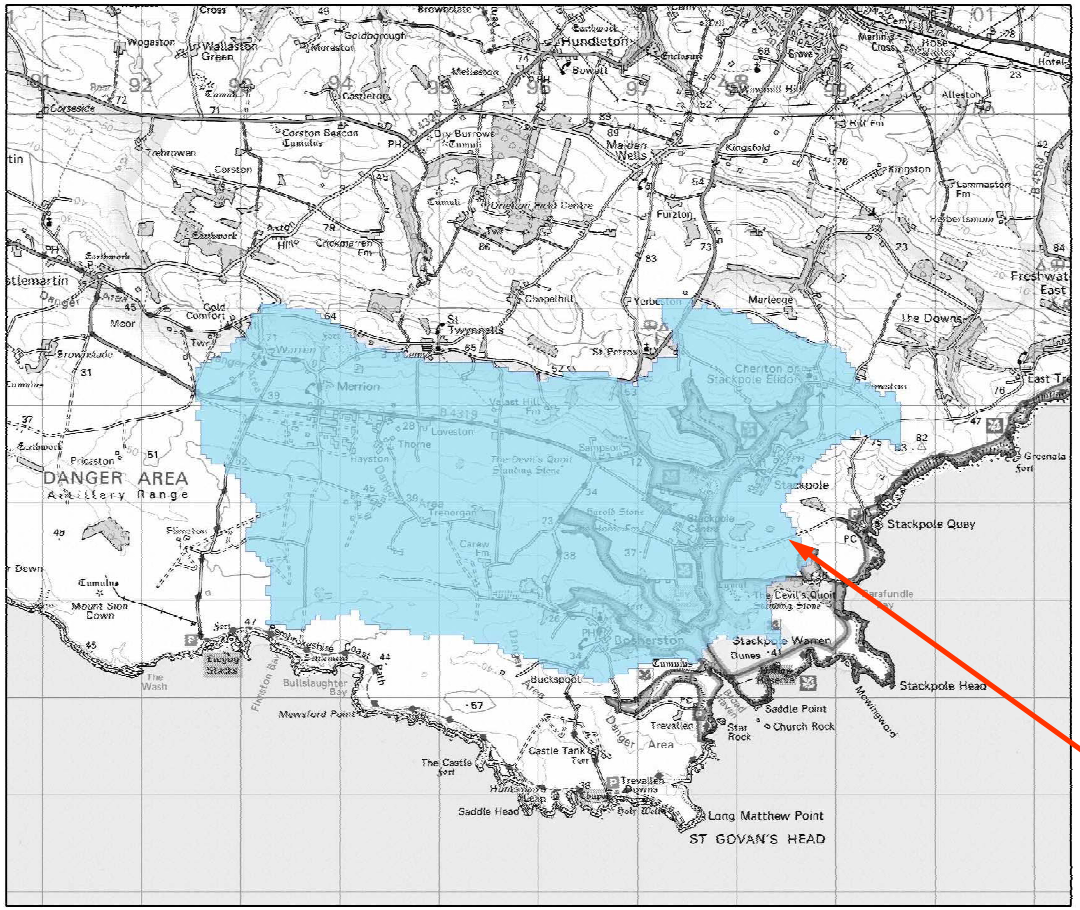




What happened to the lake ecology?

- 1950 - 1970, abundant Charophyte / *Nymphaea alba* dominanted submergent plant community in the Western and Central Arms of the lake. Dominance by broad-leaved *Potamogeton* species *(P. natans, P. crispus)* in the Eastern Arm with some areas supporting *C. globularis*
- 1970 – 1980, filamentous algal mats on over- become a problem in the Eastern Arm, with reduced species diversity and highly abundant production in the submergent plant community
- 1980 – 1996, 'weed' cutting to suppress plant production in the Eastern Arm leads to the generation of blue-green algal blooms and extensive filamentous algal mats. Problems transferred to the Central Lake and started to extend up the Western Arm with loss of some of the Charophyte beds
- 1984 – 2000 Stackpole STW diverted to the sea; old fish ponds excavated as sediment traps in the Upper Eastern Arm; 'weed' cutting programme continued and extended to the Central Lake; outflow from the Eastern Arm diverted under the bed of the Central Lake to discharge onto the beach
- 1996 – 2009
  - Lack of flows from the STW, and Eastern Arm outflow to the lake, and continued infilling with sediment reduces summer water levels, leading to dessication of Chara meadows
  - Blue-green algal blooms continue to cause problems in the Eastern Arm and Central Lake but do not extend into the important Charophyte areas in the Upper Western Arm and Central Arm

What did they miss?



- Restoration efforts have focused on reducing P loads to the lake from

  (1) Point sources

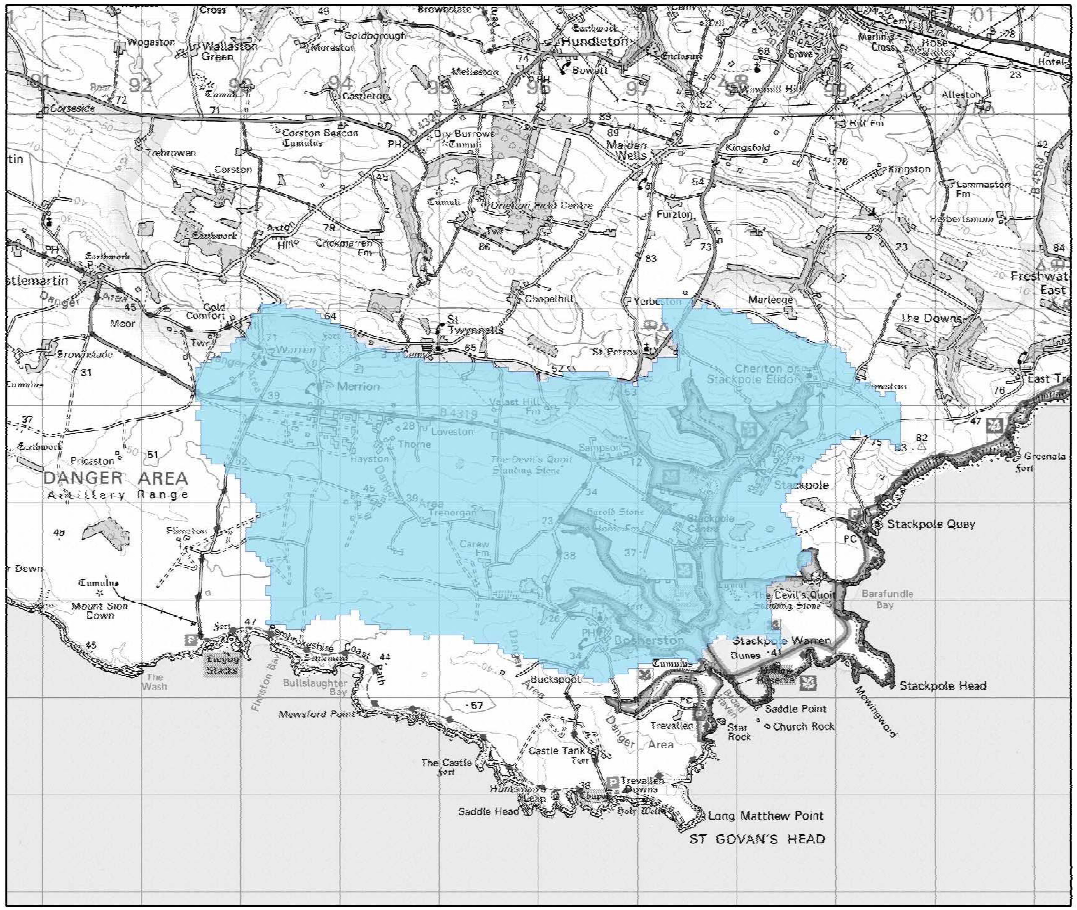
  (2) Internal P release from sediments

  (3) Internal recycling of P in plant materials

- Restoration has also focused on reducing the rate of sediment infilling

- Site owners/managers have no control over continuing P and N flux from diffuse agricultural sources in the catchment

New measures to control nutrient enrichment of Bosherston Lily Pools: Bosherston NVZ, from 1 January 2009



Appeals allowed up to 31 March 2009

Measure	Barton Broad	Bosherston Lily Pools
Diversion of STW to Sea	Yes. N. Walsham STW, 1980	Yes. Stackpole STW, 1984
P stripping at STW	Yes, at 4 STW	No other main STW in catchment
Sediment trapping	No	Yes. Excavation of sedimentation lagoons and old fish ponds
Sediment dredging	Yes. 350,000 m^3	Yes. 15,000 m^3 to Summer 2008l
'Weed' cutting	No	Yes
Biomanipulation	Yes	No
On farm reduction of N loss from agricultural land	No	Some improvements to slurry handling on NT land
On farm reduction of P loss from agricultural land	None to 31 December 2008	Some improvements to slurry handling on NT land
NVZ	New from 1 Jan 2009 appeals allowed up to 31 March 2009	New from 1 Jan 2009 appeals allowed up to 31 March 2009
Ecological targets met?	Partially, with ongoing costs Only in biomanipulated areas	No, but further decline halted (?) in sensitive Charophyte areas
Costs to date	€ 7 million	€ 2 million