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The Restoration of Loch Leven, Scotland, UK

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Abstract.
This paper reviews the progress made towards the restoration of Loch Leven, the largest lake in lowland Scotland, over the last 20years. In particular, the importance of direct regulation and of setting water quality objectives and targets. Various means of engaging with stakeholders and the general public are also considered. Success criteria and catchment management initiatives are described and briefly reviewed.

1. The water quality issues

Loch Leven is the largest lowland loch in Scotland, with a surface area of approximately 13.3 km^2 and a catchment area of about 145 km^2. 80% of the catchment is agricultural land, 11% woodland, and 2% urban areas. The farming activities included dairy and beef cattle, sheep, and arable cropping (cereals, grass, brassicas and potatoes. The loch is very shallow (mean depth 3.9 m) with a relatively low flushing rate, ranging from 0.9 – 2.6 loch volumes per year over last 60 years (Sargent and Ledger 1992). Loch Leven is a National Nature Reserve, a Ramsar site and a world renowned brown trout fishery. The nature conservation status of Loch Leven is largely due to the major summer breeding population there of diving ducks (about 1,000 pairs, mainly tufted duck *Aythya fuligula*) plus the wintering populations of waterfowl too. Dabbling ducks and coots, are heavily dependant on the presence of macrophytes in the lake, as are the *c.* 400 mute swans that gather there to moult in autumn, and the 200 or so whooper swans that visit in winter. West (1910) reported 23 species of submerged macrophytes, many abundant and colonising the loch to depths of 5m; by 1966 only 3 species were easily located, and nowhere was the vegetation dense (Morgan, 1970). Allison and Newton (1974) reported the virtual disappearance of the large flock of late summer moulting mute swans (*Cygnus olor*), reduced use of the loch by pochard (*Aythya farina*), and a decline in numbers of coots (*Fulica atra*); birds dependant on water plants (see table 1). Further background and historical information about the loch is available in Loch Leven IBP Project (1974) and on the Scottish Natural Heritage website at www.snh.gov.uk.

Table 1. Decline in peak numbers of coots (*Fulica atra*) in Loch Leven, 1955-72. (After Allison and Newton, 1974).

Period	Maximum autumn peak in numbers of coots
1955-1962	2000
1966-72, excl. 1971	270
1971	400 (good weed year)

The loch receives drainage from farms, small towns and villages, a scattered rural population and runoff from fields, forests and uplands. The main pollutants of concern were phosphorus (associated with algal blooms and loss of water clarity for submerged macrophytes), pesticides (including agricultural insecticides and industrial mothproofing agents), unsatisfactory sewage discharges, plus local pollution incidents involving a variety of pollutants.

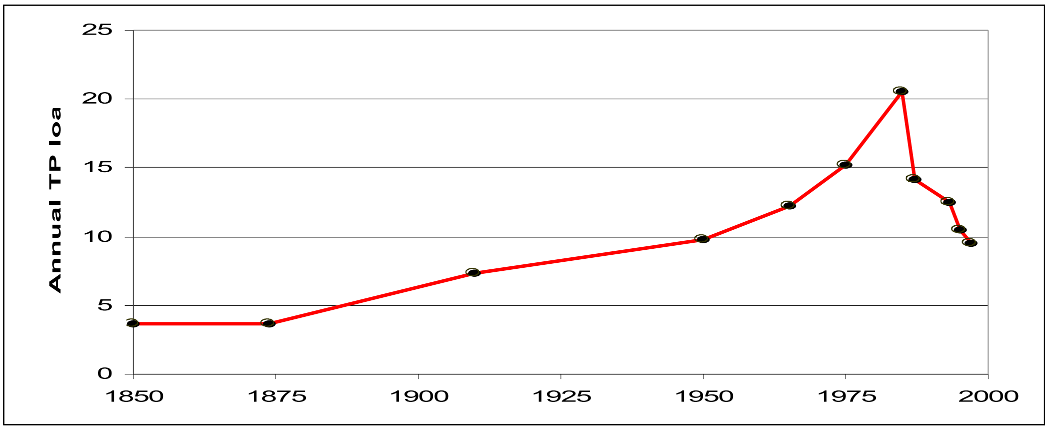
The most important pollution source was a textile mill in the local town of Kinross (D'Arcy, 1991) that until the 1990's discharged without treatment a mix of chemicals including phosphorus and mothproofing agents, *via* one of the main inflows, the South Queich. The mothproofing agents are believed to have contributed to the poor ecological quality of the South Queich. Possible impacts in Loch Leven, itself, are thought to include the loss of *Daphnia* from the zooplankton until the early 1970s. The contamination of Loch Leven by mothproofing agents also raised concerns about bi-accumulation within the loch ecosystem and the possible health risks to anglers taking the much sought after Loch Leven trout.

The textile mill was also identified as a major source of phosphorus entering the loch and promoting the development of troublesome algal blooms (Bailey-Watts *et al*. 1987). Sewage from the growing population of the towns and villages was also a contributory source of phosphorus, together with runoff from the farmland). High N and P application rates, plus pesticide applications were characteristic, especially in the sub-catchment of the intensively farmed Greens Burn tributary. Soil erosion, again especially in the Greens Burn catchment, was also a contributory factor for P losses into the loch and possibly for turbidity and indirect impacts on macrophytes in the loch. A brown trout survey in the catchment found some deformed trout fry in Greens Burn, thought to be consistent with pesticide pollution (Freshwater fisheries Laboratory, Pitlochry, pers. com.).

3. Controlling of major point sources and the case for regulatory actions

Bailey-Watts *et al*. (1987) suggested that a reduction in the total phosphorus (TP) load to the loch would lead to a reduction in algal biomass, and hence efforts should be made to reduce the external P load to the loch. Earlier regulatory effort at the textile mill had involved establishing a TP effluent concentration limit of 10 mg l^{-1} (but no load limit), and encouraging voluntary actions at the mill to reduce risks of TP getting into the loch. The limit was revised to a lower figure of 2 mg l^{-1} and a maximum permissible loading value was also established. The new TP limit was set at a level that would preclude the use of the phosphorus-based bleaching process while still allowing a reasonable practical level of P to be present in the drainage from the mill. This was followed up with enforcement action and, from 1987 onwards, major and lasting improvements at the mill were achieved (D'Arcy, 1991). This was the major turning point reversing the steady rise in external P load (Figure 1).

Figure 1. Long-term changes in total phosphorus input to Loch Leven; data prior to 1985 are derived from palaeolimnological records (Bennion, *pers. com.*)



The use of moth-proofing agents was the next issue to be addressed and the company decided simply to stop using them. This had a double benefit. It represented a significant cost saving to their business and, at the same time, improved water quality (D'Arcy *et al*., 1999). The moth-proofers used at the mill over the decades prior to the cessation altogether, in 1988, are shown in Table 2 (after Fozzard, 1994). The sequence of improvements in water quality is reflected in the Biological Monitoring Working Party (BMWP) system field scores for the

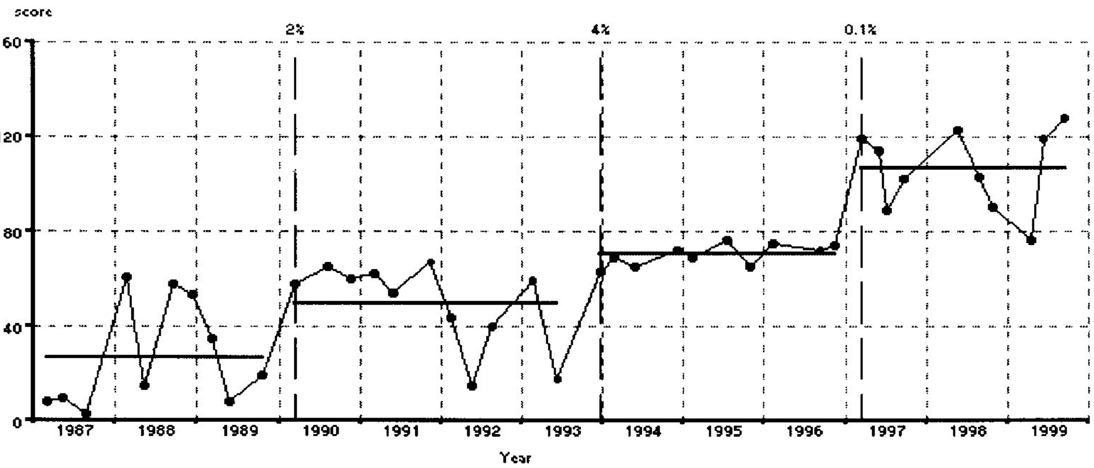
South Queich from a point just below the effluent discharge and immediately prior to the confluence with the loch (Figure 2).

Table 2. Moth-proofing agents discharged into Loch Leven from the mill at Kinross between 1950 and 1988.

Mothproofer	Active ingredient	Period in use
Dielmoth	Dieldrin	1950's -1964
Eulan WA New	Chlorphenylid	1964-1980
Mitin LP	Chlorphenylid Flucofenuron	1980-1988

Later improvements in the South Queich followed as a result of the commissioning of a full-scale effluent treatment plant at the textile mill, the use of better farming practices at poultry rearing and other premises, and the provision of fencing to exclude livestock from streams in parts of the catchment.

Figure 2. Biological Monitoring Working Party (BMWP) field scores for the South Queich at the Hecks; the plots show significant step changes in values at the 95% confidence level over time.



Enforcement action was also taken in 1988 and 1992 (in relation to an oil spill, a sewage discharge and an insecticide incident). The regulatory work was important and represented a turning point in the history of pollution problems in the loch, establishing an even handed approach across all sectors in the catchment. It showed, in a cost-effective way, that pollution prevention was a requirement, not merely an aspiration. Whilst regulatory work was undertaken with the sewage utility, requiring improvements in Kinross (cessation of Kinross South septic tank discharge and transfer of flows into the new Kinross works), and agreement on a new treatment works for the next largest settlement, Milnathort, no formal discussions were held about setting P limits for those sewage works.

4. 'Scum Saturday' and consequences

On Saturday 13th June 1992, a senescent bloom of the blue-green alga *Anabaena flos-aquae* drifted ashore at Kinross, in warm sunny weather, causing unpleasant odours and smothering the inshore area in an unattractive scum. When tests showed that the bloom was toxic, a variety of watersports (planned as a once only exception to the normal nature reserve prohibited activities) had to be cancelled (LLAMAG 1992). The bloom is thought to have occurred in response to a prolonged period of warm, still, weather that had favoured stratification within the loch, and the associated development of anaerobic conditions in the surface sediments. These conditions are conducive to the release of P from the loch sediments, associated with the changes in redox conditions in the sediments.

There was a major outcry from the general public, and from an alliance of nature conservation and angling organisations. Consequently, the Loch Leven Area Management Advisory Group (LLAMAG) was formed: a stakeholder group to review facts about water quality, causes of algal blooms, etc. and possible remedial measures. Tables 3 and 4 summarise the measures considered by LLAMAG in 1992-3.

Table 3. 1993 appraisal of primary remediation measures identified by LLAMAG as likely to improve water quality at Loch Leven (*later decisions in parenthesis)*.

Option	Costs	Kg TP Removal as % External Load	Environmental Costs & Comment	Status of Option
P-Reduction at Kinross STW at Milnathort STW Total	£2M	6.6 k gd^{-1} 2.6 k gd^{-1} 9.2 k gd^{-1} 21%	None	Approved and actions taken
Increased flushing	Not costed	Insignificant due to lack of additional water.	Flooding risks below Loch Leven.	Not possible.
STW Diversion (a) Kinnesswood (b) All STW's	£3.2M	1.0 kg d^{-1} 14 kg d^{-1} 32%	River pollution risk, and Minor reduction in flushing of loch	Superseded by decision to build new Milnathort STW
River Treatment	£60k	5.0 k gd^{-1} 12%	Loss of arable farmland – gain of wet meadows.	Evaluated by SNH *(rejected)*
Iron Salt Injection		None 10^3 x total external load 'immobilised' in loch sediments?	Toxicity for loch flora and fauna. Doubt as to the stability of the iron-phosphate deposits formed by treatment.	Rejected.
Dredging loch sediments	£10M +	50,000 Kg (10^3 x total external load in upper 10 cms).	Loss of invertebrates & macrophytes, increased turbidity, cost to industry	Rejected.
Harvesting Blooms	£150, 000		Only achievable at times of blooms; disposal ?	investigation necessary. *(rejected)*

Some of the ideas put forward were clearly impractical, others inappropriate. Lake sediments were recognised as the largest phosphorus source, but all actions to control that source were prohibitively expensive and / or undesirable from other considerations. Amongst the rejected ideas, the provision of riparian buffer zones was subsequently achieved.

Table 4. 1993 appraisal of secondary remediation measures identified by LLAMAG as likely to improve water quality at Loch Leven.

IDEAS	Comments & status
Barley straw / bioremediation / sealing P-rich sediments with calcite / maintaining high oxygen concentrations in surface sediment	Impractical or unproven techniques: *rejected*
Algicides / introduction of plankton eating fish / removal of predatory fish to enhance zooplankton grazing on algae	Inappropriate to nature conservation priorities for lake management: *rejected*
Buffer strips on farmland (but impractical?)	*rejected initially, but subsequently achieved*

Before making any decisions on the options for remedial measures, it was clearly imperative that some idea of the size of TP load reductions necessary should be estimated: what benefits would be likely to accrue from what sort of reductions?

5. Setting water quality targets for Loch Leven

Initially, it was unclear whether a restoration effort could be attempted at Loch Leven and, if so, what sort of environmental targets should be set for the loch. The main ecological value of the loch depends on the waterfowl and they, in turn, depend on the macrophytes. Low water clarity severely restricts the area of the loch bed that is able to support rooted plants, i.e. macrophytes. So, the key ecological objective for the loch was to increase water clarity sufficiently to allow the macrophytes stands to re-establish themselves in deeper water. Rooted macrophytes (*Chara aspera*) had once grown at depths of 4.5 m (*c*. 1900) but, by the 1960s, this depth had reduced to less than 2 m. Chambers and Kalff (1985) suggested that, for charophytes, a depth of colonisation of 4.5m corresponded to a Secchi disc transparency of 2.5m. ($\log z = 0.87 \log D + 0.31$, where z is the depth of colonisation (m) and D is the mean summer Secchi depth (m)). This relationship was used to calculate and an agreed target secchi disc depth of 2.5 m. Using the OECD (1982) relationships for Secchi depth and other parameters, additional target values were determined for TP (40µg l^{-1} annual mean, based on 12 samples per year) and for chlorophyll a (15µg l^{-1}, also based on12 samples per year) (LLAMAG, 1992). Finally, having set the water quality targets as above, the implications for the external TP load were determined. In 1985, the total external load was about 20 tonnes y^{-1}. It was predicted that, to achieve the required water quality targets, the external load would have to be reduced to about 9.5 tonnes y^{-1}. That was achieved.

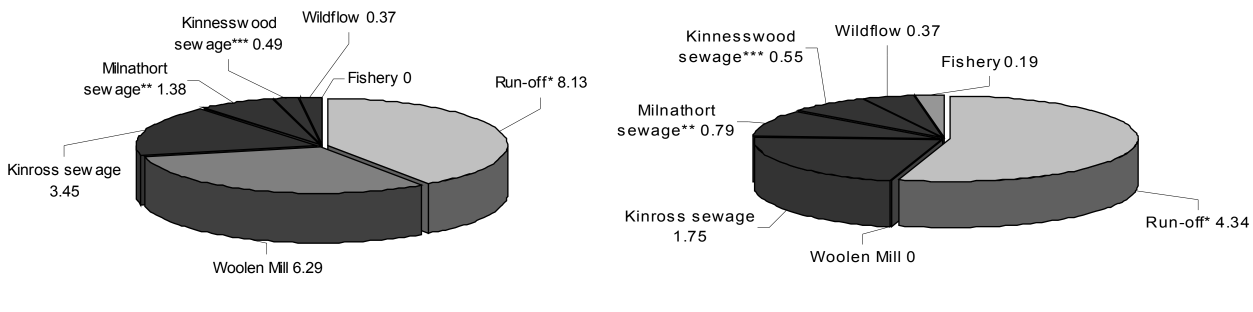
6. Control of phosphorus from municipal sewage discharges

The key task was to review the discharge consents for each treatment works and impose TP discharge limits. A 'Best Available Technology Not Entailing Excessive Costs (BATNEEC) approach was taken, based on a review of current best practice for nutrient removal at sewage treatment works. A limit of 2 mg l^{-1} was established as a pragmatic standard, and also establishing a load limit . The value was and was also consistent with the industrial limit set earlier for the textile mill. Figure 3 shows the reductions in external load achieved between 1985 and 1995. The significant reduction in phosphorus from river-borne sources in 1995, in comparison with 1985, probably reflected the lower rainfall; run-off varies significantly from year to year. The upgrading of Milnathort STW was completed in September 1995. Phosphorus dosing kit was retrofitted at Kinross STW, but capital expenditure was needed to build a completely new STW at Milnathort, replacing the old one.

Figure 3. **Estimated external phosphorus loads to Loch Leven in 1985 and 1995; values expressed in tonnes**. **(a) 1985 – Total phosphorus load = *ca*. 20 tonnes y^{-1} (b) 1995 – Total phosphorus load = *ca*. 8 tonnes y^{-1}**

(a)

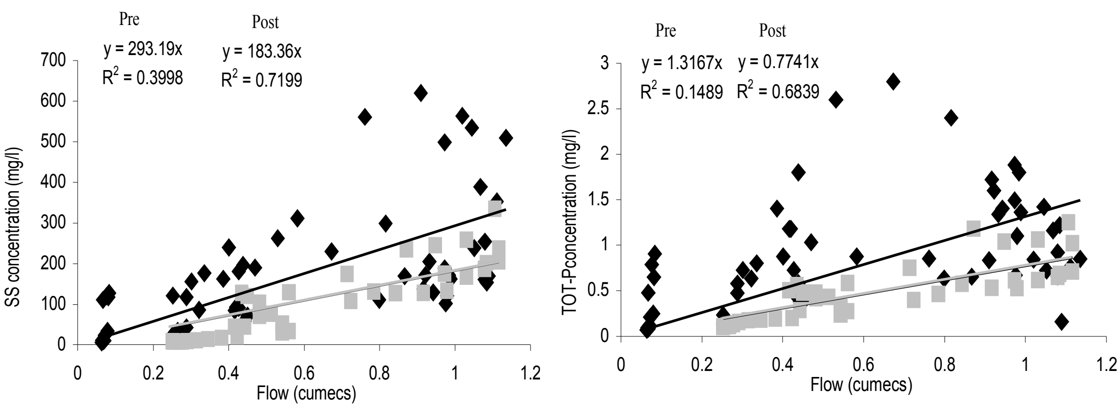
(b)



7. The control of diffuse sources

River borne P loads remained the major proportion of the loading, assuming ever more significance as the overall size of the load reduces. Principal components are: septic tanks, soil erosion, farm steadings, field middens, slurry spraying and livestock in fields. A survey of all farms in the Loch Leven catchment was undertaken (1991-2) and found that there were few direct effluent discharges, but many individually minor but probably significant issues at farm steadings and also in fields. Initial remedial efforts were targeted at steading point sources, and field middens. The buffer strips initiative was started in 1993 as a 3 organisation partnership, (FRPB / FWAG / SAC), targeting set-aside requirements, as well as farmer voluntary actions. In 1996-8 the idea was further extended via the catchment management plan (CMP) project that superceded LLAMAG, seeking targeted applications for government funds for habitat creation. 7.3 ha of buffer zones, of 3-30m width along the small tributary stream, the greens burn, were established. The effectiveness of the measures is indicated in figure 4. Intermittent catastrophic falls in BMWP scores for the burn have almost ceased since the buffer strips were provided too (preventing suspected overspraying by pesticides).

Figure 4 Pre and Post establishment of riparian buffer strip linear regression analysis of pollutant concentration and flow: (a) Suspended Solids, (b) TOT-P. Pre buffer strip ◆ ── , post buffer strip ■ ── .

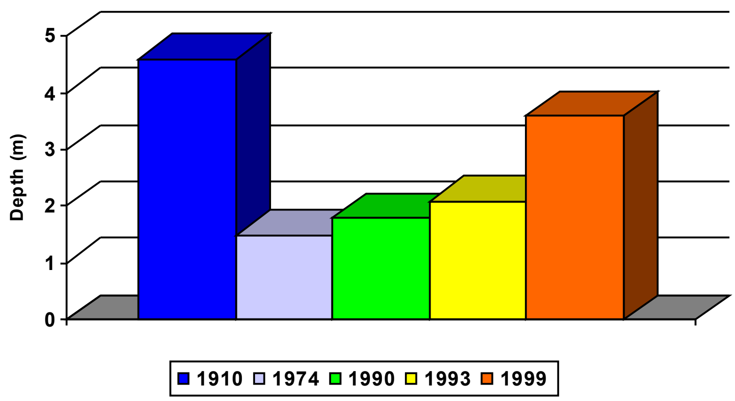


The CMP project aimed for better engagement with public interest groups and with stakeholders. Inclusive catchment management styles are a pre-requisite for success for diffuse sources. Appealing to stakeholder identity and sense of place, is a powerful driver for collective actions, and that is facilitated by catchment initiatives.

8. How can success be measured?

Targets can include the completion of new treatment works, kilometres of buffer strips, sales of low P detergents in a catchment, or numbers of farmers calling on advisory services to assess soil P status and reduce applications. But, ultimately, environmental measures have to be used to indicate success or failure. Time series data for TP and chlorophyll*a* concentrations allow comparison with the annual mean water quality targets, but the data is very variable. The quality of a loch, as indicated by total P concentration, is not simply a function of the external P load, of course, but can be massively influenced at any one time by sediment release too. Chlorophyll a values, and algal or diatom abundance, are influenced by a variety of factors at any one time. Bailey Watts (1994) presented a picture of complexity and stated at a public meeting after presenting his paper, that there was no discernible improvement in water quality in the Loch. Although a reasonable observation for the parameters reviewed, it was an alarming conclusion, given the millions of pounds spent, enforcement actions taken, changes to industrial processes and farming practices enforced and encouraged in the catchment in the antecedent years. Subsequently, a parameter has been identified that seems less prone to influence by short term P release episodes, or the rise and fall of individual algal species, zooplankton grazers or fish populations: the maximum depth at which rooted macrophytes occur in the loch. This parameter corresponds to the primary water quality target set for the loch (LLAMAG, 1993). Deteriorating water quality conditions in the loch led to the maximum depth of rooted macrophytes growth reducing from 4.5 m at the beginning of the century to about 1 m by 1974 (Figure 5). However, since the measures documented above have been taken, a significant increase in maximum rooted macrophyte growing depth has been recorded. This is believed to equate to an impressive level of recovery. Waterfowl populations have also shown some recovery.

Figure 5. The maximum depth at which rooted macrophytes have been recorded in Loch Leven, 1910 to 1999.



9. Community Engagement

LLAMAG was a stakeholder group; it comprised representatives of all of the organisations with an involvement in the problem or the solutions. It was an appropriate approach to explore scientifically and pragmatically remedial options and to develop consensus amongst the agencies. It was effective in allowing the imposition of a phosphorus standard on the municipal sewage discharges, at a time when such limits were unprecedented for towns in Scotland. Most importantly, it set up the task group to develop water quality targets for the loch. It was an appropriate and effective action in a crisis. But it was a top down, invitation only approach and did not gain acceptance with the general public or action groups. LLAMAG was replaced by an equally single issue focused project (Loch Leven Catchment Management Plan, CMP), but which did form stakeholder groups to allow a dialogue. Comparison with the agency led CMP, and other broad based multiple issues CMP processes, shows that single issue catchment planning is more focused and far less time consuming for agencies managing them. But it is at a risk of missing synergies in developing solutions, and also is far more likely to alienate other parties who may feel excluded. That was an issue at Loch Leven throughout, as local pressure groups did not feel adequately involved in the decision making processes.

10. Conclusions

The following conclusions can now be drawn concerning the water quality of Loch Leven, and the management of the catchment:

- Regulation, including enforcement action, is essential to manage pollution risks and deliver water quality targets.
- Explicit water quality targets are essential for managing pollution risks.
- Key drivers for action are ecological quality, fishery interests, and public concerns.
- Management of major point source P loads has allowed a significant ecological recovery in Loch Leven.
- Management of diffuse loads should underpin the success gained with major point sources in Loch Leven; community engagement is essential.
- There is still some way to go in the loch's recovery, and as always, uncertainty.

The following more general conclusions may also be inferred:

- Success criteria need to be established for restoration programmes. They can usefully include completion dates for capital works, compliance levels for effluent discharges, percentage take-up of voluntary measures, but must ultimately include measures of environmental quality.
- Episodic events should not confuse assessment of trends; integrating ecological parameters are preferable to chemical ones.
- Chemical parameters are nonetheless essential for setting targets and consequent target loads. It also is essential for assessing compliance with those targets; tracking progress, even if there are complicating factors that prevent clear trends in many instances for the chemical parameters and data.

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