A Strategic Water Quality Improvement Plan for Semerwater.

Words: 1999



1.0 Position Statement

Water quality of Semerwater is declining, driven by increased sedimentation and phosphorus (YDRT, n.d.). Fluctuating around 40µgl^{-1}, the total phosphorus concentrations indicate shifts towards a eutrophic state (Environment Agency, 2022). Water quality indicators demonstrate declines, including fish kills, algal blooms and degradation of aquatic organism communities (Bennion et al., 1997; SSP, 2009). Wider concerns include increased flood risk.

Designated as a Site of Special Scientific Interest (SSSI) and lying within the Yorkshire Dales National Park (YDNP), Semerwater is afforded a high level of protection under the YDNP Action Plan (YDNPA, 2021). The Water Framework Directive (WFD) is also key in directing the need for water quality improvements in lakes such as Semerwater by 2030 (McDowell et al., 2016). Biodiversity 2020 supports this in directing ecological restoration.

2.0 Literature Review

2.1 Common Issues

Increased productivity demands in marginal locations drive reliance on fertilizers (McDowell et al., 2016). In low intensity upland catchments such as Raydale this forces aquatic environments into nutrient enriched and eutrophic conditions (Wiik et al., 2015). Ecological impacts are evident with degradation of aquatic macrophyte communities and shifts to phytoplankton dominated states.

The glacial legacy also drives sedimentation and shallowing seeing increased impacts from flushing (Chiverrell et al., 2008). Deposited sediments also retain nutrients such as phosphorus and fill interstitial sediment spaces so damaging spawning grounds (Soulsby et al., 2001). Chemical and biological water quality declines are thus common concerns in lakes like Semerwater.

2.2 Common Pollutant Pathways

Understanding pollutant sources and transportation mechanisms are key in successful pollution management in Raydale.

2.2.1 Source and Mobilisation of pollutants

Fertilizer application is the principal nutrient source to land with discharge of contaminated water by farms and animal excretion also important (Pulley and Collins, 2021). Direct inputs to water originate from animal poaching or nutrient release from lakebed or wetland sediments (Marshall et al., 2014; Surridge et al., 2007). This internal source is enhanced by hypolimnion anoxia from stratification or mixing by wind and flushing (SSP, 2009). Sediments originate from areas of low erosional resistance, often seen in agricultural or forested areas.

Pollutants are mobilised by solubilisation, physical detachment and incidental losses (Haygarth et al., 2005). As seen in Raydale, high rainfall and agricultural practices enhance these processes thus increasing sediment detachment (YDRT, n.d.).

2.2.2 Transport of Pollutants

Nutrients and sediments are transported by water flow pathways (Figure 1). Surface pathways are facilitated by low infiltration capacities on compacted land or in low resistance channels. Subsurface transport occurs through permeable soils or drains or at depth through regolith or bedrock.

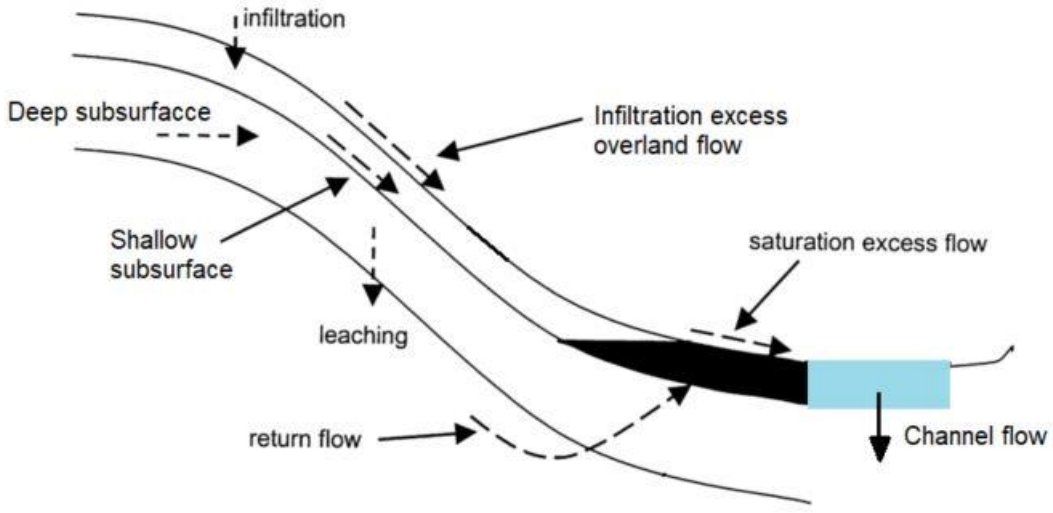


Figure 1. *Conceptualisation of flow and pollutant transport pathways (adapted from Dougherty et al., 2004).*

2.2.3 Locating Key Pathways in Raydale

Greatest nutrient inputs occur on the lower slopes where fertilizer use is greatest (Figure 2). Transport is facilitated by overland flow, enhanced by soil compaction as

inferred from Coverdale (Gao et al., 2015). By concentrating and increasing flow energy, erosion risk is also greater. Hillslope-lake coupling along the east and west shorelines enable direct transfer into Semerwater as supported by sediment tracing (Pulley and Collins, 2021). Whilst evidence suggests limited transport by tributary channels (SSP, 2009), sampling may not represent the peak discharges where greatest transport occurs thus these pathways are also highlighted (Figure 2).

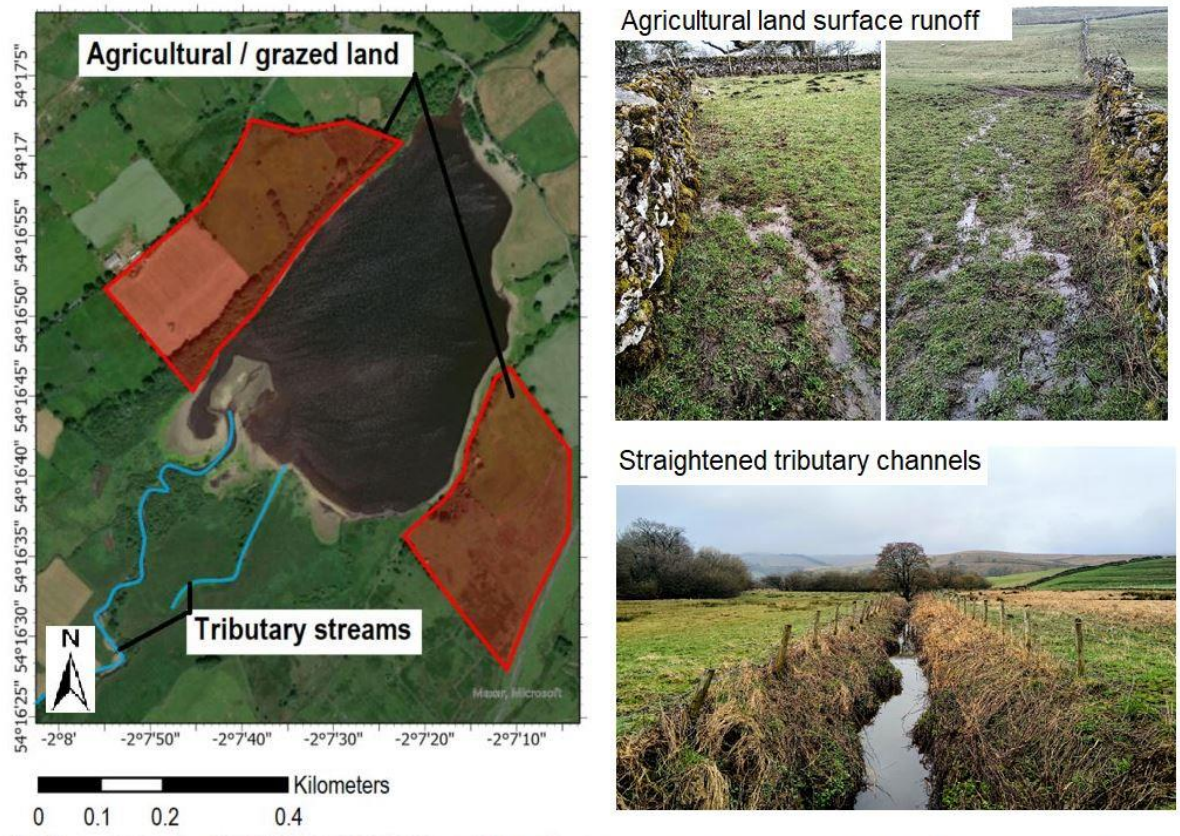


Figure 2. *Identifying source and pathways for nutrient transport.*

Sediment also originates from riverbank erosion (Figure 3). During felling stages of the commercial forestry in upper Raydale, sediment mobilisation may also be increased (Pulley and Collins, 2021). Eroded sediments are then transported through the fluvial network with increased magnitude during flood events (Bracken et al., 2015).

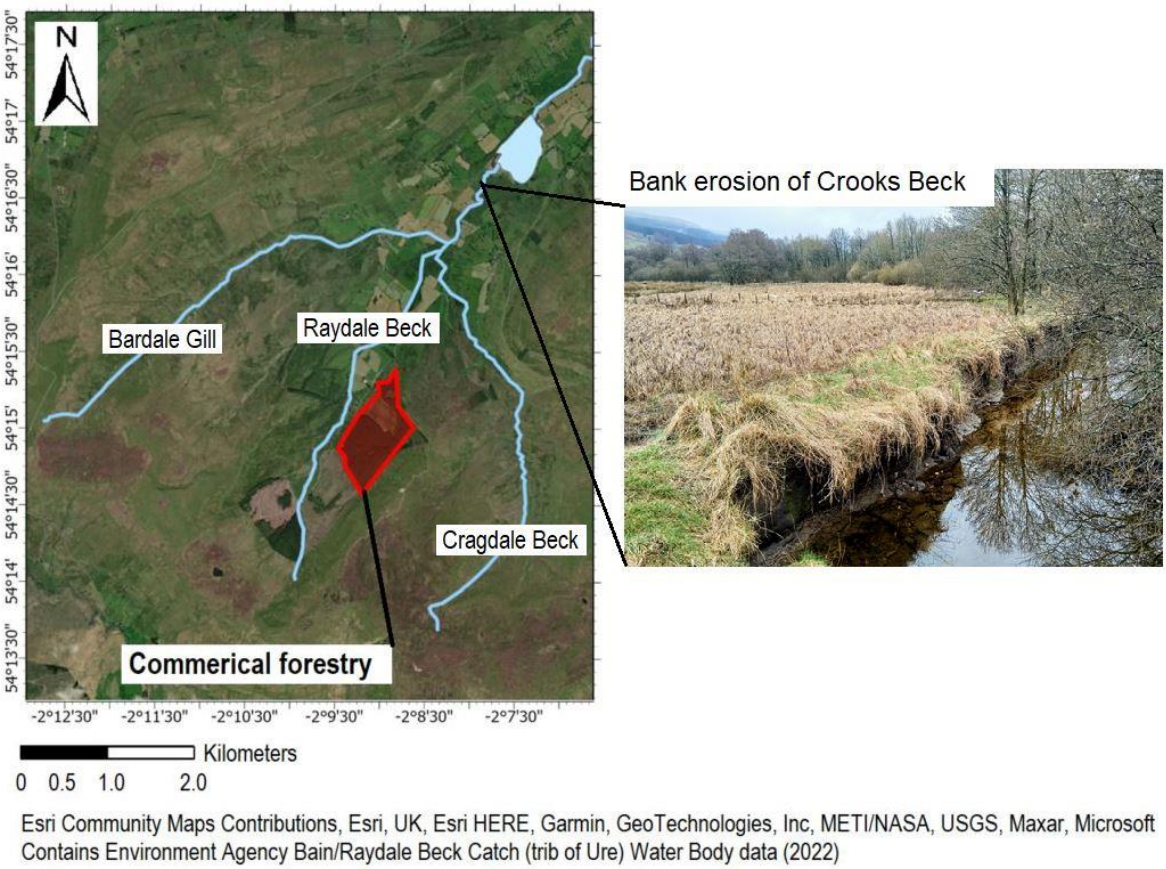


Figure 3. *Locating sediment sources and pathways.*

2.3 Semerwater: Unique Water Quality Drivers

As a marl lake, resultant of the limestone bedrock (Pentecost, 2009), historic phosphorus inputs are adsorbed to lakebed sediments. Increasing weather extremes however promote release of these with the amplified bioavailability and turbidity directly degrading the ecology (Atkins, 2002; Wilson, 1995). Heavy rainfall also increases pollutant mobilisation and transport. A higher catchment population compared to similar lakes, also increases the need for sewerage infrastructure (Wilson, 1995). Septic tank effluent may therefore be a nutrient source to Semerwater (Wilson, 1995).

2.4 Managing Diffuse Pollution

Diffuse pollution management targets all stages of the source-mobilisation-delivery continuum allowing a range of solutions and benefits (Table 1).

Table 1. *Solutions and key benefits for water quality.*

	Solution	Nutrient source	Sediment source	Surface transport	In lake benefit	Peak flow	*Co-benefits
Agricultural practice	Timing	✓		✓			
	*Fertilizer reduction	✓					
	*Soil management	✓					
	Integration			✓			
	Lake additives	✓			✓	✓	
	Dredging	✓	✓		✓		
Infrastructure	*Fencing	✓	✓	✓			
	Riparian buffers		✓	✓		✓	✓
	Contour planting		✓				
	Leaky barriers		✓	✓	✓	✓	✓
Land use	*Woodland creation		✓	✓			✓
	Wetland creation		✓	✓	✓	✓	✓
	*Headwater management		✓				
	Agricultural de-intensification	✓	✓	✓			

** Indicate solutions already implemented in Raydale*

** Co-benefits include management of legacy pollution and wider advantages such as biodiversity, carbon sequestration*

2.4.1 Adapting Agricultural Practices

Timing fertilizer application and integration with soils sees 1240 and 174tyr^{-1} phosphorus reductions (Haygarth et al., 2009). In the Rhine catchment the effectiveness of such actions produced 100% reductions in lake phosphorus over 35 years (Petri, 2005). Despite some fertilizer plans currently in place in Raydale, the improvement delay may explain the currently limited observable impacts (SSP, 2009). Reduced fertilizer use and soil management through liming, reducing soil compaction and soil stabilizers also provide similar benefits (Table 1) (Burgess-Gamble et al., 2018).

In-lake solutions including addition of iron or zirconium enable nutrient immobilisation in lakes like Semerwater with dredging removing phosphorus and reducing flushing (Yang et al., 2015). Damage to the ecology and long-term repletion however make these solutions often unsuitable (Thorne et al., 2014).

2.4.2 Infrastructure Development

Online and offline runoff management such as contour planting, riparian buffers, leaky barriers and grip blocking provide water quality benefits (Burgess-Gamble et al., 2018). Reductions of 20% in nutrient transfer by riparian buffers and 3.6mgL^{-1} of phosphate storage by leaky barriers highlight these (Peter et al., 2012; Burgess-Gamble et al., 2018). Peak flow reductions of 30% also reduce erosion and flushing (Kitts, 2010). Fencing to limit poaching, contour planting and restoration of 221ha of Fleetmoss demonstrate initial progress in Raydale (YDRT, n.d.).

Infrastructure developments include increased fertilizer storage to support timing solutions and improvements in contaminated water management. Once implemented, these are effective and long lasting.

2.4.3 Land Use Management

Current land-use change in Raydale includes woodland creation (SSP, 2009). In the Pont Bren catchment, runoff reductions of 78% for afforested plots demonstrate clear water quality benefits (Marshall et al., 2014). Through water filtration and storage, wetland creation also improves water quality (Table 1). Agricultural de-intensification directly reduces fertilizer inputs and soil degradation. However, despite long-term benefits, failure to address legacy pollution will delay observed improvements.

2.5 Land Management in Raydale

Solutions implemented in Raydale are promoted through Countryside Stewardship (CSS) and Catchment Sensitive Farming (CSF) schemes. Ten farms are under a CSS with 60% of the land managed under agri-environment programmes (SCP, 2009). Nationally, CSF achieves 36% and 25% reductions in sediment and phosphate respectively, demonstrating the importance of the schemes in Raydale (Mansfield and LeCocq, n.d.).

Knowledge gaps however include under-representation of pollutant sources stemming from limited knowledge of septic tank characteristics in Raydale (McDowell et al., 2016). Current studies may also incorrectly disregard the sediment sources from commercial forestry and transport of pollutants by tributaries. Furthermore, no assessment of the current wetland as a source of nutrients has been made. Inference of soil compaction from Coverdale also limits the spatial understanding.

3.0 Action Plan

3.1 Prioritising Management Solutions

By considering the principal water quality drivers, ten solutions have been prioritised aiming for the greatest improvements in the lake and tributaries (Table 2).

Table 2. *Ten key actions identified in the management of water quality in Raydale.*

Management action		
Agricultural Practice	***Catchment Infrastructure***	***Land Use Management***
Reduced fertilizer application	Fencing	Wetland restoration
Timing fertilizer application	Riparian buffers	Afforestation and woodland management
Structural and chemical soils management	Online structures	Agricultural de-intensification
	Fertilizer storage improvements	

3.2 Cost-Benefit Analysis

Temporal restrictions, resources and spatial challenges of diffuse pollution management demand efficient implementation of solutions. Key benefits of prioritised solutions (Table 1) are contrasted with the economic, social and environmental costs.

3.2.1 Agricultural Practices

Reduced fertilizer purchasing combined with plant uptake of residual phosphorus identify reduced usage as low-cost solutions (Haygarth et al., 2009). With reductions in nutrient sources, cost-effectiveness is quantified at £0kg^{-1} P reduction producing one of the most economically viable solutions for Raydale (Haygarth et al., 2009).

Timing fertilizer application also demonstrates strong cost effectiveness and is quantified at £16kg^{-1} P reduction (Haygarth et al., 2009). Cost is however increased by improved farm infrastructure requirements. Soil management needs additional support with identification of low pH soils and severe compaction thus increasing the cost.

3.2.2 Catchment Infrastructure

Offline solutions and online structures present low costs with leaky barriers around £150 each (Highways England, 2021). Considering only nutrients, cost-effectiveness of riparian buffers is quantified at £5kg^{-1} P reduction (Haygarth et al., 2009). They also trap sediment and reduce peak flows (Table 1). In contrast, on farm infrastructure developments are some of the most costly. By not directly reducing nutrient sources, benefits are only considered alongside those of timing solutions, providing low cost-effectiveness.

3.2.3 Land Use Management

Constructed wetlands propose a high-cost solution with investments up to £100 m^{-2} (Mackenzie and McIlwraith, 2015). Water quality benefits do mitigate this with the cost-effectiveness of phosphorus reduction estimated at £93 kg^{-1} (Haygarth et al., 2009). Co-benefits of flood management and increased biodiversity are quantified economically at £407 and £304ha^{-1}yr^{-1} respectively increasing cost-effectiveness (Morris and Camino, 2011). These additional advantages for water quality promote cost-effective long-term benefits only otherwise achievable by implementing a range of solutions. By extending the current wetland into unproductive land around Crooks Beck, concerns over reduced land productivity may also be mitigated. Environmental costs should be considered through developed understanding of nutrient dynamics in the wetland.

At £4000ha^{-1} for broad-leafed woodland creation, afforestation provides similar benefits to wetland creation at lower costs (Haw, 2017). The economic incentive is increased by income from the carbon and social benefits. Concerns over habitat destruction for species such as Curlews and loss of farm income does highlight wider costs. Similar concerns are seen with agricultural de-intensification driving the cost-effectiveness for phosphorus reduction to £12,700 kg^{-1} (Haygarth et al., 2009). The societal impacts also contradict aims of the YDNP in historic and cultural conservation

(YDNP, 2021). Failure to address legacy pollution may still require implementation of other solutions. This is considered one of the least viable solutions for implementation in Raydale under current economic and social structures.

3.3 Implementing Management Actions

No single action can remediate pollution in Semerwater. Actions are spatially diffuse requiring significant stakeholder input. Key locations for implementation are identified in Figure 4 with discussion of the advantages and costs directing a multi-stage action plan centred on water quality improvements by 2030 (Table 3). Based upon a design and evaluate structure, the plan works to only implement higher cost solutions should lower cost actions prove ineffective.

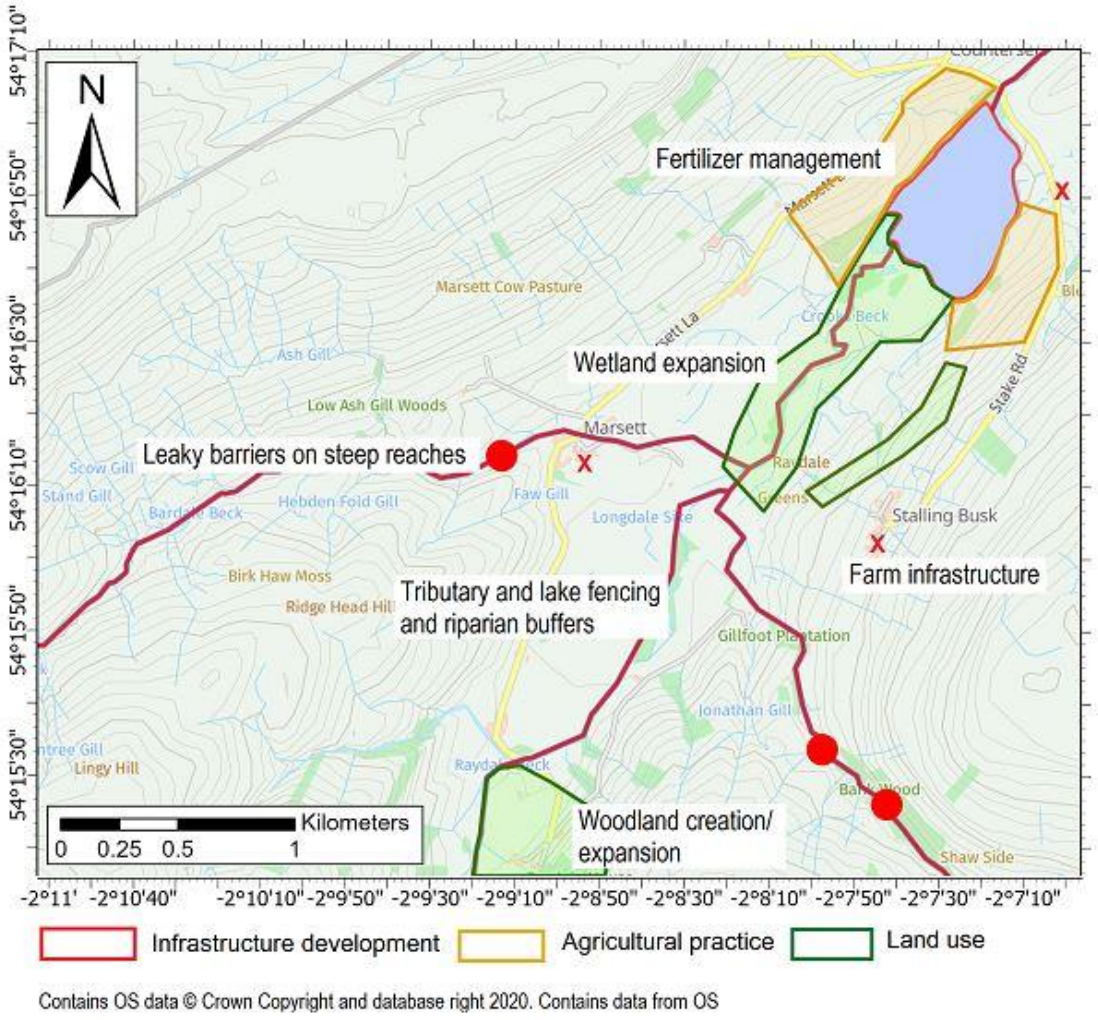


Figure 4. *Identifying key locations and actions required for pollution management.*

Table 3. *Multi-level action plan timeline designed to achieve water quality improvements by 2030.*

	Year	*Agricultural Practice*	*Catchment Infrastructure*	*Land Use Management*
Stage 1	2022	**Research input** – identify areas of high erosion risk	**Fencing** – continue fencing **Riparian buffers** – begin planting of riparian vegetation	**Research input** – identify sediment from commercial forestry and areas suitable for afforestation
	2023	**Reduced application**	**Research input** – identify influence of tributary pollutant transport	**Research input –** investigate nutrient dynamics of the current wetland area
	2024		**Online structures**	**Wetland restoration and expansion**
	2025			
Stage 2	2026	**Soil management** – monitor previous effectiveness and supplement with soil stabilisation and liming where needed	**Fertilizer storage** – as a supplement to timing	**Research input** – investigate effectiveness of previous land management
	2027	**Timing** – supplement previous practices with timing fertilizer application		
	2028			
Stage 3	2029	Continue current suitable practice	Maintain condition of fertilizer storage	**Agricultural de-intensification** – de-intensify agriculture should previous management so no improvement beginning with dairy farming
	2030 +			

3.3.1 Resource Requirements

Stakeholders share vested interests in Semerwater's water quality and share responsibility for remedial action. Ultimately farmers must implement agricultural practice adaptations and be receptive to solutions proposed on their land. Support for this should be provided by conservation organisations such as the YDNPA as already successfully seen with CSF. Science, agriculture and policy should be bridged by research organisations to improve efficacy of solutions.

With regards funding, each solution proposed (Table 3) falls under some form of support. Schemes such as Environment Agency's Riparian Tree Planting Programme enable riparian zone development whilst afforestation is supported by UK Government and Forestry Commission England (Defra, 2021). Wider support is available under CSS Higher Tiers, demonstrating the importance of continuing such schemes in Raydale (GOV.UK, 2020). These are unlikely to be sufficient, so organisations benefiting from agricultural practices in Raydale such as Wensleydale Creamery may also be responsible for economic support.

Long term policy developments are also needed. Currently Defra's Path to Sustainable Farming (Defra, 2020) integrates agricultural and environmental needs although this must also encompass economic and cultural support unique areas such as Raydale, potentially even questioning the viability of agriculture. Legislation governing phosphorus use in sensitive catchments may also be valued. Policy development could also fill gaps in domestic sewage regulation and commercial forestry in national parks, as identified by the Forestry Commission and National Parks England Accord (Forestry Commission, 2018).

4.0 Closing Comments

Efficient implementing solutions will support water quality improvements in Raydale by 2030 thus meeting WFD objectives. Full restoration will however take many decades thus must be acknowledged in management decisions.

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