Multi Criteria Analysis of Rural Private Water Supply Treatment Options – A Case Study

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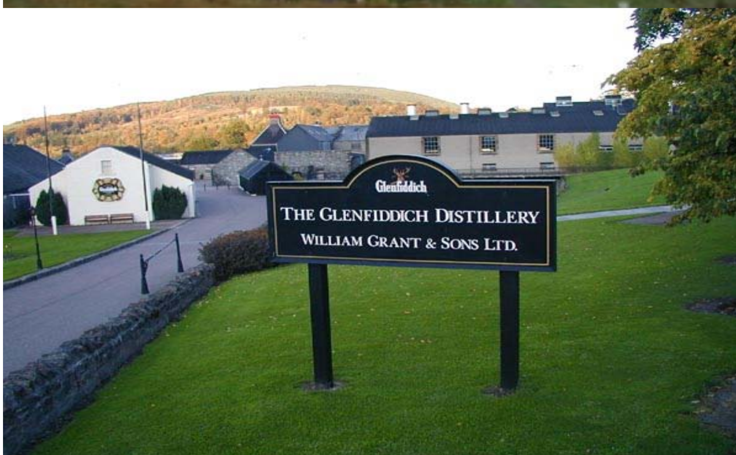
Challenges

- Rural communities in Scotland
  - Development and growth dependent on access to clean reliable drinking water source
    - Small commercial activities (tourism, food and drink, whisky!)
    - Housing

- Landscape – multiple diffuse pressures on drinking water sources
    - Agriculture
    - Peatlands
    - Septic tanks


Glenfiddich
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Drinking water quality in Scotland

Private water supplies:

Type A: (50+ commercial) – Monitored and failures reported

Type B: Domestic premises only – Monitoring not required

Parameter	Public supply (% compliance)	Type A – Private (% compliance)	Type B - Private (% compliance)
Overall compliance	99.89	93.97	87.86
Coliform bacteria	99.55	75.77	56.88
E. coli	99.99	[illegible]	78.37
Colour	100.00	[illegible]	83.18
pH	99.98	83.21	73.21
Iron	99.63	86.56	85.94
Manganese	99.70	92.70	87.73

Colour, peat, organic acids + Chlorine = Disinfection by-products

Table 1 Compliance with drinking water quality parameters in Scotland 2014

How can we identify the more sustainable water treatment technologies for small rural communities?

Social, Environmental and Economic Issues

Wide range of stakeholder opinions

CREW CENTRE OF EXPERTISE FOR WATERS

The Scottish Government
Riaghaltas na h-Alba

Project Aims:

- Assess the drinking water treatment technology landscape
- Develop an approach for assessing the technologies across a range of operational scenarios

The James Hutton Institute

CREW CENTRE OF EXPERTISE FOR WATERS

The Scottish Government
Riaghaltas na h-Alba

Outcome:

A generic decision support process based on 3 deliverables:

1. An inventory of technologies for further evaluation

2. A set of selection criteria to be applied to decision making processes

3. A MCDA tool for future decision making

The James Hutton Institute

Methodology Stage 1

- **Technology Scan – what technologies are potentially suitable to provide treatment**
- Consultation with experts, generation of a Technology Inventory suited to Scottish rural water treatment issues
- Identification of Selection Criteria
- Short-list of technologies for a specific site
- Decision making workshop with key stakeholders

Technology Scan

To identify current treatments and trends in innovation

- Academic and grey literature
- Technical literature from water treatment technology providers
- Recent water industry publications to identify emerging treatment technologies

In order to identify emerging and novel technologies

Technology Scan (Continued)

- Websites and product offerings from key actors in Scotland and internationally were reviewed to identify additional candidate water treatment technologies
- A number of online water technology expert forums were also consulted

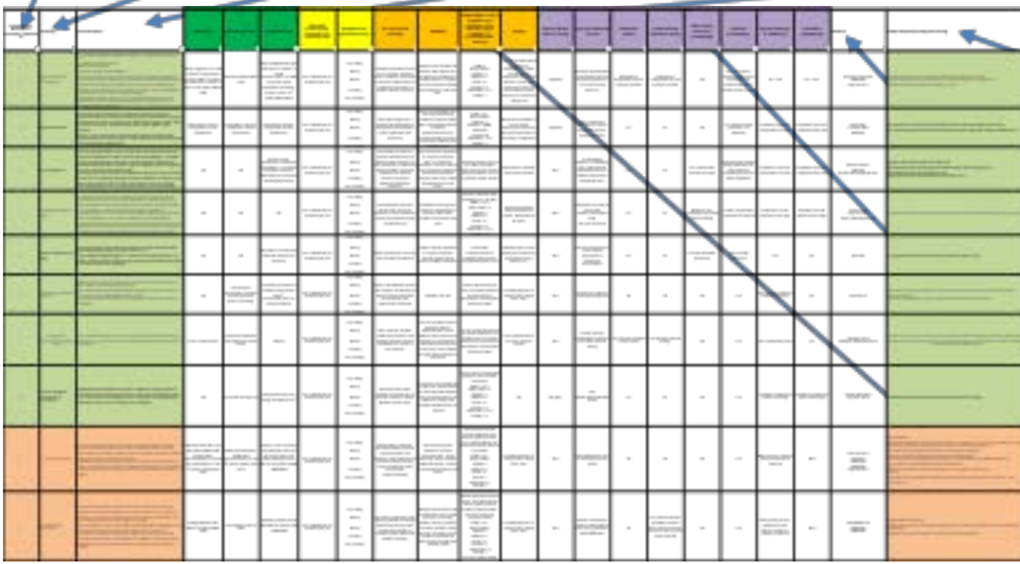
Type (Filtration F, Disinfection D, Alternative or additional A)

Technology

General description

Economic Criteria

Social Criteria



Companies providing the technology

Supporting References

Environmental Criteria

Performance Assessment Criteria

Result of Technology Scan

Assessment Criteria

Economic		
Capital cost (£)	Maintenance cost (£r)	Operational cost (£)

Social	
Affordability (cost per year per household - to be calculated by user)	Willingness to pay (determined by users)

Performance			
User input required (complexity)	Adaptability	Reliability/ability to achieve compliance	Durability

Assessment Criteria

Environmental							
Resource utilisation (Water % recovery)	Energy use (kWh/m^3) (ND = no data)	Chemical use (Yes/No)	Chemical transport requirement (Yes/No)	Impact on water environment (Low/Med/High)	Solid waste (Low/Med/High)	Physical footprint (m^2) (Low/Med/High)	Visual impac (Low/Med/H gh)

Methodology Stage 2

- Technology Scan – what technologies are potentially suitable to provide treatment?
- **Consultation with experts, generation of a Technology Inventory suited to Scottish rural water treatment issues**
- **Identification of Selection Criteria**
- **Short-list of technologies for a specific site**
- Decision making workshop with key stakeholders

Stakeholder Workshop 1: Attendees

Representatives from:

- The Scottish research community (CREW)
- Scottish Water
- The Drinking Water Quality Regulator (DWQR)
- A private water consultancy
- The enterprise agency involved in Scotland's Water Innovation Centres
- Water Industry Commission for Scotland

Stakeholder Workshop 1: Tasks

- Reviewed the list of candidate technologies identified by the technology scan

(Resulted in the final technology inventory)

- Identified candidate Technologies for a case study catchment

- Identified potential sustainability assessment criteria

Fact Sheet: Catchment information

Description:

The catchment location is a mix of Private Water Supply and septic tanks. Community is composed of residential, tourist accommodation and a distillery.

There may be a potential impact on rivers.

Number of residents:

200

Water Quality Issues:

- *10 Bacterial Failure*
- *1 chemical*
- *1 other*

Case Study Catchment Carragmore

Case Study Catchment

- A mix of Private Water Supply and septic tanks
- Community is composed of residential, tourist accommodation and a distillery
- There may be a potential impact on rivers
- Number of residents: 200
- Water Quality Issues:

  10 Bacterial Failure

  1 chemical

  1 other

Stakeholder Workshop 1: Output

1. Final Technology Inventory

2. Candidate Technologies -Case Study Catchment

Stage	Filtration	Disinfection	Addition Treatment (pH correction)
Potential Technologies	Sand Filtration	Chlorine Disinfection	Lime Filter
	Ceramic Membrane Filter	UV	Chemical Addition
	Microfiltration	UV LED	

3. Sustainability Assessment Criteria

Sustainability theme	Criteria	Description	Units
Economic	Capital Cost	Capital cost of equipment and install	£
	Maintenance Cost	Maintenance costs per year	£/year
	Operational Cost	Operational cost (e.g. consumables, energy)	£/year
Social	Affordability	Ability of householders to pay for services delivered	% of househol budget
	Willingness to pay		£/unit of reduc risk
Technological/ performance	Complexity (user input required)	ow medium	basic/int/adv c low/med/higl
	Adaptability	tial and ualitative)	1-5
	Reliability, ability to achieve compliance	Ability to meet drinking water quality standards (parameter specific - no treatment, good, very good, excellent/complete treatment)	0, +, ++, +++
	Durability	Design life, years expected to operate successfully	years
	Water resource use	Consumption of raw water resources	% recovery
	Energy use	Energy required in process	kWh/m3
	Chemical use	Chemical use (qualitative or quantitative)	yes/no or kg/m
	Chemical transport requirement	Impact on air quality (sulphur dioxide, nitrous oxide emissions) and climate change (CO_2 emissions)	yes/no or miles/m3

Methodology Stage 3

- Technology Scan – what technologies are potentially suitable to provide treatment?
- Consultation with experts, generation of a Technology Inventory suited to Scottish rural water treatment issues
- Identification of Selection Criteria
- Short-list of technologies for a specific site.
- **Decision making workshop with key stakeholders on the case study catcahment**

Stakeholder Workshop 2 Attendees

- **A technology expert**
- **Local residents**
- **A representative form the Local Enterprise Agency**
- **Representatives from Scottish water**

Stakeholder Workshop 2 Tasks

- To determined the weighting of each category and each criteria

- To discuss and score each potential technology against criteria

- To review the output of an MCDA analysis using the scores and weightings.

MCDA Procedure

WORKSHOP 1

WORKSHOP 2

POST-WORKSHOP ACTIVITY

MCDA Procedure

MCDA Procedure

Criteria Ranking and Weighting

Delegates were briefed on the characteristics of the catchment and the list of MCDA to be used criteria to compare each option.

Delegates were invited to record individual opinions of firstly a ranking and then a suggested weightings of criteria on Data Sheets

The stakeholder group was then required to reach a consensus discussion on weights and to record this on a group version of the Data

MCDA Procedure

Criteria Ranking and Weighting

Activity 2 A - Criteria ranking and weighting				
Rank Criteria: Rank each criteria 1,2,3, 4. Weight Criteria: Weight the criteria by % to make 100.				
Rank	....	....	....	....
	Economic	Social	Technical	Environmental
Weight	.......%	.......%	.......%	.......%

Activity 2 B - Criteria ranking and weighting			
Rank Criteria: Rank each criteria 1,2,3,4 / Weight Criteria: Weight the criteria by % to make 100.			
Economic			
Rank	....	....	....
	Capital Cost	Maintenance Cost	Operational Cost
Weight	.......%	.......%	.......%
Social			
Rank	....	....	....
	Affordability to householders	Willingness to Pay	User input required
Weight	.......%	.......%	.......%
Technical performance			
Rank	....	....	....
	Adaptability	Reliability of the system	Durability of the system
Weight	.......%	.......%	.......%

MCDA Procedure

Scoring of Options

1. Delegates were reminded of the characteristics of the catchment and briefed on the list of candidate technologies that had been identified

2. The following information was issued and discussed by delegates for, initially, the first stage of the treatment process:

- An information sheet on the general features of each of the candidate technologies
- A data sheet, providing data for each candidate technologies drawn from the Technology Inventory

MCDA Procedure

Scoring of Options

2 (continued)

- A Data Sheet on which each delegate recorded their own opinions on the rank order and then and score for each of the technologies against each of the criteria

3. Each group was then required to reach a consensus on the scores for each technology and record this on a group version of Data Sheets 3B

MCDA Procedure

Scoring of Options

Fact Sheet: Ceramic Membrane

Category
Filtration

Why is it needed?
Filtration of particles, bacteria, protozoa, and some chemical compounds

About the technology
Ceramic membranes consist of multiple layers of one or more ceramic materials such as Al_2O_3, TiO_2, ZrO_2, SiO_2 or combinations (composite membranes). They may be discs, plates or tubular.
They can be combined with other technology in a hybrid system (i.e. coagulation, advanced oxidation)

Advantages: superior mechanical strength, chemical resistant, reported to have lower operational and maintenance costs than polymer membranes

Disadvantages: high capital cost, less operational experience compared to polymer membranes as they are relatively new

Operation in the crossflow filtration mode, maintains high filtration rate compared to direct flow filtration

Operational and cost data tends to be derived from large scale plants, processing millions of litres per day; less evidence of use on small/community scale.

Operation and Maintenance considerations
Mechanical stability allows use at pressure;

Minimal chemical cleaning, extended backwash intervals

Longer membrane lifetime than polymers

Application at a wide range of pH

High water recovery

(Techneau ceramic membranes (above) and pilot plant (below)) (2007)

Ability to treat M/C/A

Microbial	Can produce high purity water, removing bacteria, protozoa and viruses
Chemical	Can remove Fe, Mn, some heavy metals, sediment
Aesthetic	Reduces turbidity

MCDA Procedure

Scoring of Options

Activity 3A: Individual decision on technology ranking
Rank the technology against each criteria. 1 = Worst to 9 = Best

	Economic			Social			Performance			Environmental							
Technology	Capital cost (£)	Maintenance Cost (£/yr.)	Operational Cost (£/yr.)	Affordability cost per year per household	Willingness to pay	User input required (complexity)	Adaptability	Reliability (ability to achieve compliance) (--, -, +, ++, +++)	Durability	Resource utilisation (Water % recovery)	Energy use (kWh/m^3)	Chemical use (kg/m^3)	Chemical transport requirement	Impact on water environment	Waste	Physical footprint (m^2)	Visual impact (Low, med, high)
Ceramic membrane filter	£11000-£21000 (About 16% higher than MF)	£ 150.00	£ 300.00	£4.50	Very willing Willing Neutral Unwilling Very unwilling	Safe handling of membranes, periodic monitoring and inspection	Can accommodate higher flux than polymer membrane, therefore can achieve more per m^2 surface area, however they are more expensive.	Fe/Mn +/+ Heavy metals - Organics - Bacteria +++ Viruses - Protozoa +++ Taste/Odour -/- Turbidity +++	Able to accommodate higher flux, membrane life time up to 20 years	97-99.9%	0.1-0.2 kWh/m^3	Low (may be used in cleaning e.g. citric acid, NaOCl)	minimal, cleaning chemicals	about 1% wastewater	Low	Small	Low
Microfiltration	£5000-£18500	£ 150.00	£ 400.00	£6.50	Very willing Willing Neutral Unwilling Very unwilling	Periodic monitoring and inspection, replacement of filter (cartridges or modules)	Suitable for small community; can be modular; Scalable by addition of modules	Fe/Mn +/+ Heavy metals -- Organics -- Bacteria +++ Viruses- Protozoa +++ Taste/Odour -/- Turbidity +++	Membrane life 7 to 8 years or less depending on source water. Membrane integrity testing required periodically to check for wear or damage.	92 to 95% average	0.22-0.9 kWh/m^3	Low (some may be used in cleaning)	minimal, cleaning chemicals	about 5-8% wastewater	Low	Small to med (larger than ceramic)	Low
Sand filtration	£27000-£31000	£ 100-2545	£438	£ 5-30	Very willing Willing Neutral Unwilling Very unwilling	Skimming top layer of sand, once per year, and washing for reuse	Once installed may not be easy to expand capacity, May require to add additional system (or have sufficient redundancy built into design)	Fe/Mn ++/++ Heavy metals - Organics - Bacteria ++ Viruses ++ Protozoa ++ Taste/Odour ++/++ Turbidity +++	Very durable, low tech system. Periodic skimming and renewal of sand may necessitate two filters. Requires start up period for biofilm layer to form.	>99.5	minimal	nil (non chemical method)	None	minimal	Low	Med-large ($9m^2$)	Med

Note: Estimates based on Average Scottish consumption (150 litres per person per day) and small community system (up to 100 homes, 200 pe)= 200 x 150 x 365 = 10,950,000 litres or 10950 m^3 per year. Data provided are not absolute, and provided for comparison purposes only.

MCDA Procedure

Scoring of Options

	Economic		
Technology	Capital cost (£)	Maintenance Cost (£/yr.)	Operational Cos (£/yr.)
Disinfection option 1			
Disinfection option 2			
Disinfection option 3			

MCDA Procedure

MCDA Analysis

Two methods were used for the MCDA

1. An initial analysis at the workshop using the Simple Multi-Attribute Rating Technique (SMART Output)

2. The initial SMART analysis was verified and tested post-workshop using TOPSIS and Risk Analysis using sensitivity testing

MCDA ANALYSIS

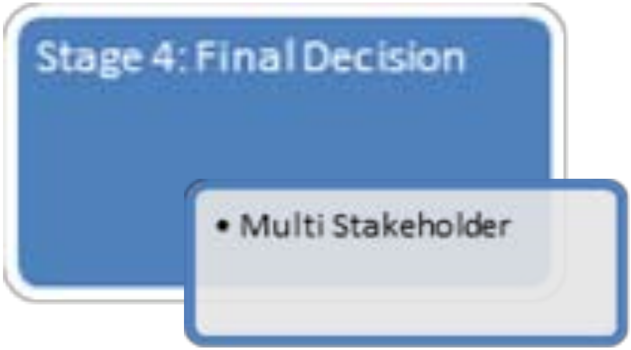
Simple Multi Attribute Rating Technique (SMART Output)

Label 1: n criteria	criteria label/tech stage 1	C1	C2	C3	C4	C5	C6	C7	C8
Enter weights									
	weights	0.10	0.60	0.09	0.09	0.10	0.06	0.07	0.16
Enter preference data [1=low, 9=high]	Alternative 1	5	9	9	9	9	8	2	4
	Alternative 2	9	9	5	5	6	9	9	1
	Alternative 3	1	1	1	1	1	1	1	9
Smart calculation performed per alternative		0.5	5.4	0.81	0.81	0.9	0.48	0.14	0.64
		0.9	5.4	0.45	0.45	0.6	0.54	0.63	0.16
		0.1	0.6	0.09	0.09	0.1	0.06	0.07	1.44
		SMART							
		SCORE	RANK						
		11.31	1						
		9.83	2						
		4.75	3						

MCDA ANALYSIS

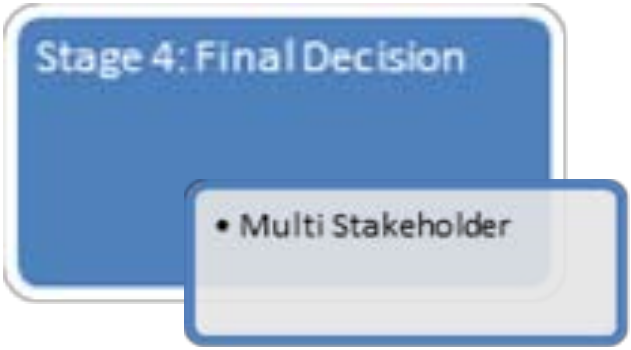
TOPIS Output

	C1	C2	C3	C4	C5	C6	C7
min/max optimal value	min	min	min	min	max	max	max
Enter weights	0.10	0.06	0.09	0.09	0.10	0.06	0.07
Alt 1	16000.00	150.00	300.00	4.50	9.00	1.00	6.00
Alt 2	11750.00	150.00	400.00	6.50	7.00	4.00	9.00
Alt 3	29000.00	1322.50	438.00	17.50	1.00	9.00	1.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 1	256000000.00	22500.00	90000.00	20.25	81.00	1.00	36.00
Alt 2	138062500.00	22500.00	160000.00	42.25	49.00	16.00	81.00
Alt 3	841000000.00	1749006.25	191844.00	306.25	1.00	81.00	1.00
(Sx2))1/2	35143.46	1329.41	664.71	19.20	11.45	9.90	10.06
Alt 1	7284.43	16.80	135.40	1.05	7.08	0.10	3.31
Alt 2	3928.54	16.80	240.71	2.20	4.28	1.62	7.46
Alt 3	23930.49	1305.81	288.61	15.95	0.09	8.18	0.09
Alt 1	728.44	1.05	11.85	0.09	0.71	0.01	0.23
Alt 2	392.85	1.05	21.06	0.19	0.43	0.10	0.52
Alt 3	2393.05	81.61	25.25	1.40	0.01	0.51	0.01
A+	392.85	1.05	11.85	0.09	0.01	0.01	0.01
A-	2393.05	81.61	25.25	1.40	0.71	0.51	0.52
Alt 1	112619.84	0.00	0.00	0.00	0.00	0.26	0.08
Alt 2	0.00	0.00	84.91	0.01	0.08	0.17	0.00
Alt 3	4000778.33	6490.41	179.73	1.70	0.49	0.00	0.27
Alt 1	2770912.40	0.00	84.91	0.01	0.08	0.00	0.00
Alt 2	4000778.33	0.00	0.00	0.00	0.00	0.01	0.08
Alt 3	0.00	0.00	0.00	0.00	0.18	0.26	0.05
	TOPSIS SCORE	Rank					
Alt 1	0.015	2.00					
Alt 2	0.955	1.00					
Alt 3	0.000	3.00					



(i) Facilitator assembles full MCDA results, recommend the appropriate solution and circulate a brief summary to stakeholders (list as stage 1) for comments and/or confirmation of agreement

(ii) Final Decision based on feedback



Two Groups worked independently at the Workshop 2

Further MCDA testing was undertaken following the workshop and this confirmed the validity of the decision support process.

FINAL DECISION

Stage	Filtration	Disinfection	Addition Treatment (pH correction)
Selected Technology	Ceramic Membrane Filter	UV LED	Chemical Addition

General Outcomes

- Decision was the same for two separate groups
- Stakeholders found exercise surprising – technology experts had not considered local needs/priorities; Community members did not have much prior knowledge of the technology
- Investment cost was important, but other features much more important locally

Conclusions

- Technology landscape is complex, multiple options for treatment
- MCDA is useful tool for water treatment decision making on best treatment for a specific location
- No one-size fits all system – must take into account local treatment needs, technology suitability and local concerns

Thank you for listening!

Question?