Pathogen protection using ultrafiltration

at rural ground water supply - a case study

by

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Carradale is a small fishing village with a resident population of 1000, located on the West coast of Scotland near Campbeltown, Kintyre. Historically, the public water supply has been abstracted from a soft acidic coloured upland stream source and treated by conventional chemical processes using aluminium sulphate to remove the humic colour. In recent years, afforestation of the catchment significantly reduced surface water yield and increased dissolved NOM levels to such an extent that the source and treatment works could not sustain peak demand during the summer tourist season (population doubles) and supplementary water was brought in by road tanker from Campbeltown.

In order to alleviate this seasonal shortfall and to produce water which met EU water quality regulations, the availability of ground water was examined. A subsequent survey of groundwater sources in the area revealed a plentiful aquifer under croft land to the north of the village. The sole use of this land for water supply protection was unfortunately not negotiable with the crofters, which meant that there was a risk of pathogen contamination - particularly *cryptosporidium* - at the proposed borehole locations, due to the close proximity of sheep and cattle farming.

In March 2000, West of Scotland Water (WoSW) awarded a contract, under competitive tender, to *PCI-Water* to build a 270m^3/day (produced over an 18 hour period) ultrafiltration plant to provide a pathogen barrier and a treatment process to fully comply with EU water quality regulations for ground water supplied from four boreholes.

Treatment process

The works was designed to produce 18.72m^3/hr and to operate on demand from a service reservoir level signal. Water quality process design challenges were threefold, namely: soluble metal removal, the retention of particles greater than one micron diameter to protect the system from *cryptosporidium* contamination and to prevent the water being corrosive.

Soluble Metal Removal *(courtesy PCI Membrane Systems)*

Soluble metal removal

Carradale raw water is colourless with low levels of TOC, but is corrosive and has moderate to high levels of dissolved iron, manganese and aluminium due to the combined presence of old red sandstone and granite schist in the aquifer. Thus, an important part of the process design was removal of soluble metals. Soluble metal removal is achieved by the combination of chlorine oxidation and carbonate precipitation.

Borehole water is pumped to the treatment works using variable speed pumps. Only two of the four boreholes are used at any one time, the duty being rostered each time the plant starts up.

The raw water is chlorinated using 2% w/v sodium hypochlorite solution to give a free chlorine residual of 0.8mg/l in the ultrafiltration permeate. The chlorinated water upflows through a tank containing a bed of dolomitic limestone (3-5mm grit) where soluble metals precipitate as insoluble carbonates. There are two limestone tanks, each sized to be capable of providing an 11 minute bed contact time at maximum design flow. The volume of water above the limestone bed also acts as a buffer tank to enable the borehole pumps to keep running during a membrane backwash. Precipitated metals are removed from the bed by backwashing with permeate every four weeks. The membrane backwash pump is used for this purpose as well. Washwater is collected in a 20m^3 chemical waste tank and bled at a small and constant rate to a "soakaway". The chemical waste tank also accepts membrane backwash water.

The use of chlorine as a preoxidant and the formation of DBP's was investigated by undertaking THMFP studies on the raw water. These studies showed that this water had a very low formation potential. The 6-day THMFP at 5mg/l was only 17µg/l. The use of sodium hypochlorite as a preoxidant has the added benefits of providing a disinfectant residual in the final water and a reduction in biofouling on the ultrafiltration membrane.

Table 1. Carradale raw water quality

	pH	Turbidity FTU	colour Hazen	TOC mg/l	Alkalinity mf/1HCO3	A1-sol µg/l	Fe-sol µg/l	Mn-sol µg/l
Min	3.73	0.1	1	0.7	1	17	24	18
Max	7.99	4.96	11	14	203	427	5713	268
Mean	5.62	0.63	4.87	2.1	13.6	138	439	150

Ultrafiltration Pathogen barrier

Conditioned water leaves the limestone contact tank by gravity and is pumped to the membrane stack via duty/standby booster pumps.

The membrane stack consists of a total of six *HYDRAcap*™ *(Hydranautics)* vertically mounted ultrafiltration membrane housings with parallel feed and permeate manifolds. The membranes are operated in dead end mode. Each housing contains 10,000 polyether sulphone capillary membranes (length 60 inches and capillary id of 0.8mm) which provides a total membrane area of 37m^2 per housing.

Ultrafiltration Pathogen Barrier *(courtesy PCI Membrane Systems)*

The plant is designed to run at a maximum filtrate flux rate of 85 l/m².h. The membranes operate at a mean inlet pressure of 0.46 bar and a TMP of 5.2 psi. Water is filtered through the membranes in an inside to out configuration, the permeate being collected in a permeate channel which is situated in the centre of the tube bundle. Hence, conditioned water enters the bottom of the stack and leaves via the top to the permeate water tank. From this tank the water is pumped by duty/standby relift pumps to Carradale service reservoir. pH of the final water is adjusted using sodium hydroxide.

Membrane Cleaning *(courtesy PCI Membrane Systems)*

Membrane cleaning
Three automatically initiated cleaning methods are employed to remove foulants from the membrane which are as follows:

1) **filtered water backwash** - this is carried out every forty minutes of run time and involves the pumping of permeate from the permeate holding tank using a duty backwash pump in an outside to in configuration. The backwash water can exit via the top or bottom feed manifolds, thereby giving an even backwash over the complete housing. Positioning of the backwash exit is rostered. Backwash flow is approximately double the feed flow, and the backwash duration is twenty seconds.

2) chemically enhanced backwash - this is carried out once every twentyfour hours. The backwash water is dosed with concentrated sodium hypochlorite to give a free chlorine residual of 25mg/l. The membranes are soaked for five minutes in this solution then rinsed for 60 seconds prior to return to service.The washwater is dosed with sodium metabisulphite to neutralise the free chlorine.

3) chemical clean - this is carried out once every two weeks and alternates between acid (sulphuric acid) and caustic (sodium hydroxide). The membranes are allowed to soak for one hour in the dosed backwash water then rinsed for sixty seconds prior to return to service. The washwater is neutralised before collection in the chemical waste tank.

4) Membrane integrity testing
The integrity of the membranes is tested automatically once per week using a pressure hold test. The plant is stopped and the water on the tube side of the capillary membranes is purged by air over a period of eight minutes. An integral membrane will not allow air to pass. An air pressure of 0.5bar is then held for five minutes. If a pressure drop in that period is less than 50 millibar then there is no fault and the membranes are integral. A failed test is an alarm and shut down condition. In the event of a failure, each membrane housing can be tested individually to detect the location of the broken fibre. Broken fibres can be located by observing air escape from each end of the housing with the end plates removed. Broken fibres can be plugged and the housing returned to service. As well as the weekly pressure hold test, the permeate is continually monitored for breakthrough of particles >2µm diameter and turbidity.

Final Water Quality/Water Stabilization *(courtesy PCI Membrane Systems)*

5) Final water quality/water stabilisation
In common with many groundwater sources Carradale borehole water contains dissolved carbon dioxide which creates an acidic, corrosive environment which requires to be neutralised and stabilised before going into supply. This is achieved primarily by passage through the limestone tank. The calcium hardness of the water increases from about 20mg/l as CaCO3 to approx 80mg/l. The pH of the water is adjusted from a mean of 5.4 to 6.2. Further pH adjustment is necessary after the water is processed by UF membrane in order to achieve the minimum pH guideline of pH 7.5 for final water. This is achieved using caustic soda dosing. The pH setpoint is kept just below the Langelier saturation pH of 8.1 in order to prevent limescale deposition.

A 28 day performance testing period (twice daily samples of raw, conditioned, permeate and final water samples for bacteriological AND chemical analyses) began on the 11th of May 2001 and was successfully completed. The plant went into supply on 14th July 2001. Final water quality is summarised as follows:

Table 2: Carradale final water quality

	Turbidity	Hd-Total	A1-Total	Fe-Total	Mn-Total	Alkalinity
	FTU	mg/l CaCO3	µg/l	µg/l	µg/l	mg/l HCO3
Min	0.2	64	10	<10	5	167
Max	0.83	97	109	<10	17	258
Mean	0.21	74	24	<10	5.2	224

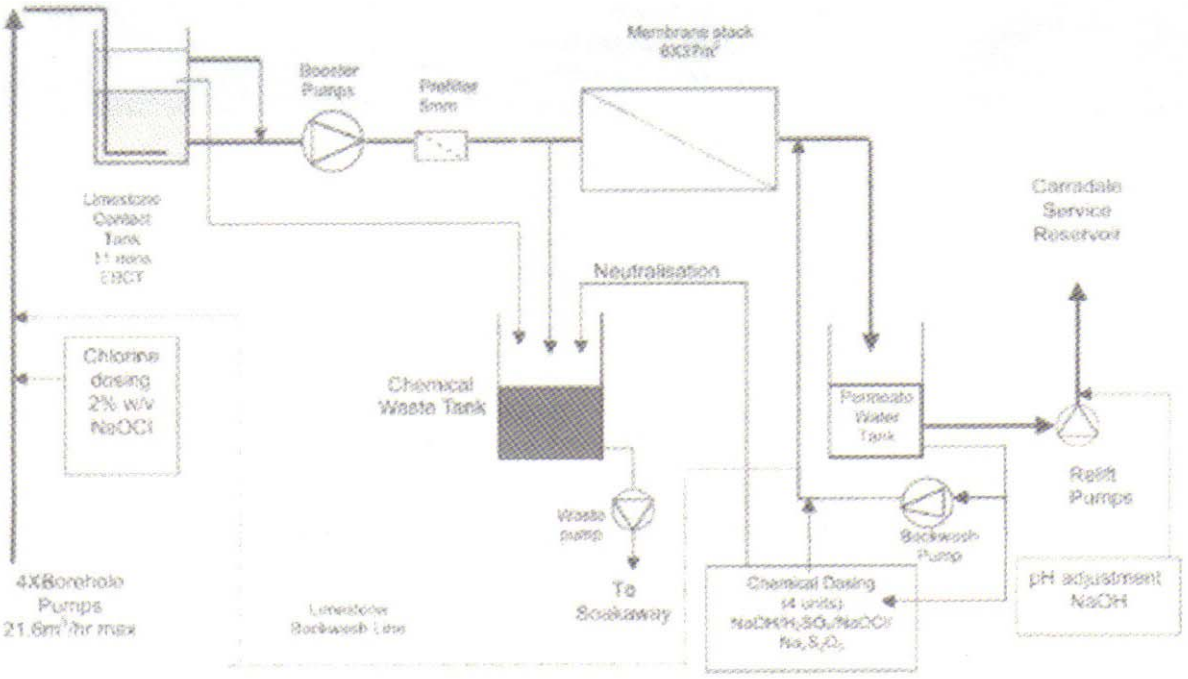

Diagram 1: Process Flow Diagram

Coliform bacteria and other pathogens such as cryptosporidium and giardia, have not been detected in the permeate or final water. All integrity tests to date have been passed. ■

Note on the authors: *Ed Irvine is West of Scotland Water, Project Developer; David Welch is Applications Specialist and Darren Reed is Sales Engineer, both with PCI Membranes, a part of PCI - Water Membrane Systems.*