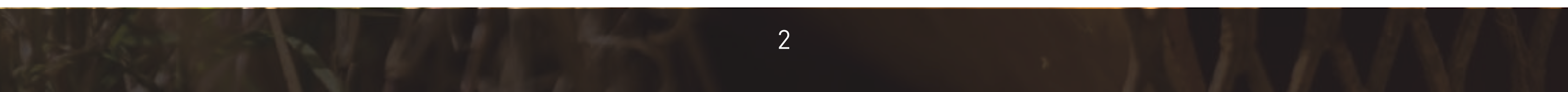
Best Management Practices for Clogging of Irrigation Infrastructure by Iron and Sulphate Bacteria

Wine Australia for Australian Wine

The Limestone Coast
Grape & Wine Council Inc.

Government of South Australia
South East Natural Resources Management Board

Cover photo: Impact of Iron Bacteria on water quality and infrastructure.
Top right: Sand filters treating groundwater before use for irrigation. Photos courtesy of Gavin Blacker and Lawrences Irrigation.



Irrigation Water Quality in the Limestone Coast Region

In the Limestone Coast region, irrigation water is obtained from underground aquifers, with the most heavily used being the unconfined Tertiary Limestone Aquifer (TLA). Irrigation water sourced from this aquifer is generally of good quality (salinity less than about 1,200 mg/L as Total Dissolved Solids). However, many irrigators face issues with irrigation water quality that affect productivity or increase the costs of infrastructure and/or labour.

These include:

- High calcium (Ca) and bicarbonate (HCO_3) concentrations that lead to precipitation of calcium carbonate scale (e.g. $CaCO_3$) and blockage of irrigation infrastructure components (e.g. drippers).
- Iron and sulphate bacteria that cause clogging and reduced performance of irrigation infrastructure (e.g. pumps and pipes).
- Elevated salinities in some areas that affect crops and increase soil salinities.

The Limestone Coast Irrigation Water Quality project has been funded by the Limestone Coast Grape and Wine Council (LCGWC), the South East Natural Resources Management Board (SENRMB) and Wine Australia. The first step in the project was an online survey designed to capture information about the extents of irrigation water quality issues in the Limestone Coast region and the approaches that are being used to mitigate these.

The results of this survey are available as a report from the Limestone Coast Grape and Wine Council website (http://limestonecoastwine.com.au). Local information obtained from the survey has been used with a review of national and international literature to develop Best Management Practices (BMPs) for managing irrigation water quality issues in the Limestone Coast region.

The full report on the development of the BMPs is also available from the Limestone Coast Grape and Wine Council website. This brochure provides a user-friendly summary of the background information and the BMPs developed for iron and sulphate bacteria issues.

Some Useful Definitions

The following reference guide provides explanations of some of the terms used in this document in the context in which they are used here. These are not necessarily full definitions.

Aquifer. An underground layer of rock or sediment which holds water and allows water to percolate through.

Biofilm. A community of bacteria that attach to a surface by excreting a sticky, sugary substance that encompasses the bacteria in a matrix.

Biofouling (and Iron Biofouling). Biofouling is any process by which there is an accumulation of material on a solid surface due to the presence of microorganisms including bacteria. Iron biofouling is just one type of biofouling and is caused by iron bacteria. Iron biofouling is usually observed as clogging with a sludgy and slimy orange-brown precipitate.

Chelating agent. Chelating agents reduce the occurrence of iron biofouling by bonding with the iron and making it unavailable for bacteria to metabolize.

Groundwater. Water occurring below ground level.

Groundwater salinity. The concentration of dissolved salts in groundwater, usually expressed in parts per million by weight or as milligrams of salts per litre of water (mg/L).

Iron bacteria. Bacteria that derive the energy they need to live and multiply by oxidizing dissolved ferrous iron. In water resource management, the problem of iron biofouling of wells or irrigation infrastructure by iron bacteria is sometimes simply referred to as 'iron bacteria' and the two terms are used interchangeably.

pH. A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid and higher values more alkaline.

Permeability. The ability of a porous material (often a rock or an unconsolidated material) to allow fluids to pass through it.

Precipitate. Cause (a substance) to be deposited in solid form from a solution or the substance that is precipitated from a solution.

Sulphate-reducing bacteria or 'sulphate bacteria'. Bacteria that can obtain energy by oxidizing organic compounds or molecular hydrogen (H_2) while reducing sulphate (SO_4) to hydrogen sulphide (H_2S).

Unconfined aquifer. Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

Unconfined aquifer Management Area. For the purpose of management and allocation of the groundwater resource, the unconfined aquifer (and the confined aquifer) in the Limestone Coast region has been divided into 'Management Areas'. For the unconfined aquifer, these Management Areas are generally based on hundred subdivisions. Groundwater resource status and condition are often reported by Management Area as it is a useful way to report spatially variable data.

Water table. The level below which the ground is saturated with water.

Well (or bore). An opening in the ground that gives access to underground water.

Iron in Groundwater and Iron Clogging

Iron (Fe) is present in the rocks and sediments that make up soils and aquifers and is therefore commonly found dissolved in the water that flows through these aquifers. The concentration of iron dissolved in groundwater is strongly dependent on the chemistry of the groundwater, particularly its dissolved oxygen concentration. Groundwater with low oxygen concentrations (e.g. from fairly deep below the water table) can contain large concentrations of dissolved iron (this iron occurs as Fe^{2+}). When this groundwater comes into contact with oxygen or mixes with more oxygenated groundwater, the Fe^{2+} converts to Fe^{3+}, which then comes out of solution as reddish-brown solid iron (oxy)hydroxide minerals. This inorganic process can occur due to changes to the groundwater flow regime or mixing in a pumping well and may cause clogging of wells, pumps and irrigation infrastructure (Appelo and Postma, 1999).

Iron Bacteria and Iron Biofouling

Certain naturally occurring bacteria, collectively known as iron bacteria, can enhance this process as they use iron in chemical reactions to produce energy. In this case, the iron precipitate that forms becomes incorporated into a biofilm, which can cause more serious clogging of groundwater abstraction and irrigation infrastructure (Steutz and McLaughlan, 2004). This is called iron biofouling. Serious well clogging problems, involving reddish-brown sludgy and slimy precipitates, often with high measured concentrations of iron bacteria, are commonly attributed to 'iron bacteria' or 'iron biofouling' (e.g. Steutz and McLaughlan (2004); Forward (2008); GHD (2010)). Bacterial iron deposits can often (but not always) be distinguished from purely mineral iron precipitates by a soft, feathery or slimy appearance, and microscopically by the presence of bacteria and certain mineral structures (Smith, 2015). Iron biofouling is the most common bore failure process across Australia (GHD, 2010) and is also a widespread issue overseas (e.g. Cullimore and McCann (1977)).

The main causes of iron biofouling are the availability of dissolved or complexed iron, the presence of the bacteria themselves, an environment that encourages microbial growth (i.e. nutrients and oxygen) and flow velocities greater than groundwater flow rates (Tyrrell and Howsam, 1994; Smith, 2015). Whilst drillers and pump contractors are often accused of transporting iron bacteria from one place to another, the most likely source of iron bacteria in a well is the aquifer around it. Aquifers with any contact with the surface or that are very shallow and with dissolved iron concentrations greater than 0.5 to 1.5 mg/L have a high potential to contain iron bacteria (Cullimore, 2000). However, drilling contractors can take steps to minimize the transport of bacteria from one well to another, recognizing that drilling equipment can never be expected to be sterile.

Iron biofouling of a submersible pump.
Source: Forward (2008) in GHD (2010).

Potential symptoms of iron biofouling include (GHD, 2010):

- Decreased flow, e.g. clogging of pumps or well screens and short pump life;
- Decreased well yield due to plugging of voids in the aquifer;
- A decrease in water quality, e.g. taste, colour, staining, odour;
- Increasing acidity and hence corrosion of bore components;
- Encrustation of bore casing, screens, reticulation and irrigation systems;
- Spontaneous slugs of brown, black or red water;

Iron bacteria are mainly found in areas of high water velocity or turbulence, e.g. within the gravel pack of a bore near the pump, in bore screens, pump inlet screens, pump internal components, discharge components and in pipelines (Forward, 2008).

100 mm pipe clogged with an iron bacteria biofilm.
Source: SA MDB NRM Board (2006).

Sulphate Bacteria

'Sulphate bacteria' are a group of naturally occurring bacteria that interact with sulphate (SO_4) in the environment and are also known to cause clogging of wells and irrigation infrastructure when pumping from anaerobic (oxygen-free) aquifers (Appelo and Postma, 1999). High flow velocities near abstraction wells provide a larger food supply in the form of dissolved organic carbon and sulphate (SO_4) for these microorganisms (Appelo and Postma, 1999). Unlike iron bacteria, they are generally not able to remain attached to pipes, etc under high flow velocities.

The Extent of the Problem in the Limestone Coast Region

The recent Irrigation Water Quality Survey indicated that 'iron bacteria' is an issue of great concern to irrigators in certain areas of the Limestone Coast, particularly around Coonawarra and Naracoorte. Here, irrigators describe the problem becoming worse in recent years. Irrigators interviewed from the Coonawarra area suggested that the problem affected a few wells in the 1960s and 1970s but became a lot worse when irrigation development increased in the 1990s.

Twenty-one of the 54 survey respondents (39%) indicated that they had 'iron bacteria' in at least one well. Ten of the 15 unconfined aquifer Management Areas covered in the survey had at least one case of 'iron bacteria' reported. The costs to businesses vary greatly depending on the severity of the problem but irrigator estimates suggested around $100/ha/yr or a total of $1,000 to more than $5,000/yr. The survey results suggested that 'iron bacteria' are not a problem in the Padthaway area and, whilst present in the Robe (Waterhouse) area, it is also not a significant problem there. Four respondents, from the Mayurra, Joanna, Wirrega and Zone 3A areas, reported the presence of sulphate bacteria in their wells. All of these occurred in conjunction with iron bacteria.

The locations of iron bacteria problems within irrigation systems varied from within the well screen (restricting well yields) and the pump (causing reduced flow rates and pump failure) to within dripper lines and drippers (affecting dripper outputs).

A pump component from the Limestone Coast region affected by an iron precipitate. Photo: Lawrence's Irrigation.

Learning More about the Iron Clogging Problem

Some irrigators report 'iron bacteria' problems in conjunction with local groundwater level declines or a need to deepen their wells in the past 10 years. This link may become an area of further investigation. Also, the role of bacteria in the iron clogging problems experienced in the Limestone Coast region needs to be confirmed so that appropriate mitigation strategies can be applied. As described above, changes to water chemistry alone can result in iron precipitation and clogging problems without the help of bacteria. However, some irrigators who had water samples tested have identified large numbers of iron bacteria in their water. Additionally, irrigators who use chlorine dosing to treat relatively severe clogging problems report improvements in the level of clogging, suggesting that at least the more severe problems may be iron bacteria related. More detailed investigations and analysis of the clogging material itself may help to confirm the importance of bacteria in individual clogging problems so that appropriate mitigation strategies can be selected.

A dripper line from the Limestone Coast region affected by iron sludge.

What Can You Do?

The following provides some mitigation strategies available for iron bacteria problems, as early evidence suggests that the severe cases of iron clogging in the Limestone Coast region may be iron bacteria related. 'Iron bacteria' is the most significant biofouling problem identified in the Limestone Coast region. However, many of these mitigation strategies also apply to sulphate bacteria.

Preventative Measures and Monitoring

Particularly if you are located in areas where iron bacteria problems have been identified, applying preventative measures during well drilling and maintenance, and monitoring water quality, bacterial numbers and well performance is important. Iron biofouling problems can be treated most effectively if caught early.

Preventative measures include avoiding screening wells across zones of different groundwater quality and thoroughly cleaning all equipment used in a well. When pumping from low oxygen parts of an aquifer, avoid introducing oxygen into the pumped water, e.g. repair leaking seals and avoid mixing with water from near the water table.

Testing for Iron Bacteria

Iron bacteria adhere to surfaces, so testing of water does not always identify an iron bacteria problem nor is it always reliable in quantifying the scale of a problem. However, the presence of iron bacteria in a water sample can be used as an indicator of a potential problem. A range of laboratories test water samples for iron bacteria. The Australian Water Quality Centre and ALS Global having been used by irrigators in the Limestone Coast region. Samples must be analysed within 24 hours of collection. If possible, a full groundwater chemistry analysis, especially total and dissolved iron, should also be carried out to better understand the chemical conditions causing a clogging problem. Important sampling protocols must be followed to ensure that results represent groundwater conditions.

Australian Water Quality Centre: Analysis of water samples can be organised by calling 1300 653 366 or emailing awqc@sawater.com.au.

ALS Global: Contact Kieren Burns on 8162 5130 (kieren.burns@alsglobal.com) to arrange for sample bottles, sample transfer and testing. Samples can be collected in the afternoon and taken to Mount Gambier where ALS will arrange for an overnight courier.

Iron precipitate ejected from a dripper line during flushing in the Limestone Coast. Photos: Gavin Blacker.

Iron bacteria tend to collect around well screens and filter packs. A downhole camera can be used to confirm the presence of iron bacteria biofilms in a well, their location and also the severity of the problem. Microscopic and chemical analysis of the clogging material to identify mineralogy and confirm the presence of an iron bacteria biofilm is the most definitive way to confirm that the problem is iron bacteria related. This can also be arranged through a commercial laboratory such as the Australian Water Quality Centre or ALS Global.

Available Treatments

The most appropriate treatment for an iron bacteria problem depends on the location of the problem. Iron bacteria usually originate in the aquifer. However, they may cause serious clogging in irrigation infrastructure (e.g. in dripper lines) as well as in the well or pump itself. A range of treatments that have been used to manage iron bacteria issues in Australia are summarized below. Unfortunately, none of the treatments completely cure iron bacteria problems and most rehabilitation attempts result in short-term solutions. Readers are referred to the full BMP report or to the product manufacturers for full details of applicability and methods of application.

Treating Groundwater Wells and Pumps

Physical Methods: The simplest treatment for clogged pumps is to remove the pump periodically and clean and replace components as necessary. Some irrigators find that doing this once every five years is sufficient to keep the problem under control and that the expense is manageable. Likewise, in mild cases where well yields are affected, well contractors can be employed to clean well screens using brushes and air surging / redevelopment.

Chemical Treatments: For serious cases of iron / iron bacteria clogging, chemical treatment is found to be successful, for example:

'Clearbore' (www.clearbore.com.au) was found by the SA MDB NRM Board in 2006 to be the most effective treatment product on the market. According to the manufacturer, this product dissolves and clears iron bacteria crusts or sludge, is biodegradable and non-toxic.

Sulphamic acid (NH_3SO_3) is used worldwide in well cleaning chemicals. It is usually purchased as a soluble white crystalline powder, which is poured down a well and allowed to slowly flow through the pump before being flushed from the bore. Acid dosing is a simple and cost-effective method, which may be effective in clearing non-biological iron deposits or those containing significant amounts of carbonate material. If the problem is iron bacteria related, acid dosing may not necessarily control bacterial numbers or clear large amounts of biofilm.

Biocides. Chlorine is the most commonly used biocide in well maintenance. Several irrigators in the Limestone Coast region report using chlorination pellets (e.g. Goldclean, Halosan and Halovac; e.g. see www.goldtecsystems.com.au) administered through automatic dosing systems to control iron bacteria problems, finding that this maintains iron deposits at a manageable level. If biofouling is light, shock chlorination alone may be effective (Smith, 2015). Here, chlorine is circulated within a well using a hose to allow proper mixing of the chlorine throughout the well. The chlorine concentration of the circulating water is measured and maintained at 50 mg/L using a simple pool chlorine test kit. The water should also be acidified with vinegar, acetic or glycolic acid to a pH of 5.5 to 6.5, which can be tested using pH test strips. Glycolic acid is also considered to be a good biocide and biofilm dispersing agent (GHD, 2010). Note: biocides will only be effective if clogging is caused by bacteria.

A chlorination system used in the Limestone Coast region, showing the automatic dosing unit and chlorination pellets. Photo: Gavin Blacker.

'Pumpmate' (http://www.biostatengineering.com/pumpmate.htm) is a product developed by Biostat Engineering consisting of copper electrodes that are dissolved by an electric current to act as a biocide.

'Boresaver' range of products (http://boresaver.com.au), manufactured by Aquabiotics Industrial Pty, for systems that are contaminated with iron oxide, manganese oxide and iron related bacteria. The Boresaver Ultra C product is reported by the manufacturer to convert iron oxides/hydroxides to soluble iron, and to dissolve the slimes that cause clogging problems. These can then be removed from the bore by either airlifting or pumping. However, one key component of this chemical is oxalic acid, which should not be used if calcium concentrations are greater than 50 mg/L (common in the Limestone Coast region) as oxalic acid can form an insoluble precipitate under these conditions. Boresaver Liquid Enhancer is a copper salt solution that acts as a biocide for severe iron biofouling cases.

Sokolan® is reported by GHD (2010) to be suitable for use in saline or hard waters and our research suggests that it is simply a dispersing agent.

If an iron bacteria problem is caught early, regular treatment and vigilant monitoring can keep it under control.

Note: chlorine and other chemical solutions are strong oxidants and can cause skin irritation and burns, and damage plants and clothing. Disposal of chlorine solutions and other treatment chemicals should be carried out carefully and following environmental regulations.

Water analyses should be carried out before and after any treatment to test its effect (Smith, 2015). After any cleaning treatment, a well should be pumped until the water is clear, and then chlorinated and allow to stand for twenty-four hours. Note: cleaning can produce significant solids that can clog filters or damage pumps.

Combined Methods: For entrenched cases of iron biofouling, combined approaches including physical agitation such as surging and combinations of chelating agents, acids and alkaline surfactants may be necessary (Forward, 2008). This is best done by professionals.

Treatments for Irrigation Delivery Systems

Chlorine solutions as described above can also be applied through irrigation systems. The following additional treatment methods are suitable for treating pumped water prior to distribution through an irrigation system.

Aeration Systems: At least one irrigator in the Limestone Coast uses an aeration system to remove iron and iron bacteria deposits from water pumped from groundwater wells before distribution through a drip irrigation system. The water is pumped into sub-surface mains, approximately 200 m long, aerated and then passed through filters. The filter material requires changing approximately every two years. The systems cost approximately $60,000, have been in place for approximately 12-13 years and are maintaining uniform dripper outputs. Aeration causes dissolved ferrous iron to be converted to insoluble ferric oxides, forcing it to precipitate out in settling tanks or pipelines to be removed by filtration before it can cause a problem in downstream infrastructure. This also removes the food source for iron bacteria, restricting the proliferation of bacterial populations.

Magnetic Water Conditioners: Several irrigators in the Limestone Coast have tried magnetic water conditioners to treat iron bacteria problems. The main supplier of these is Delta Water Systems (www.deltawater.com.au). The magnets are applied downstream of the pump and cost approximately $12,000 - $15,000 each. In general, there was little success reported for iron bacteria problems, although one irrigator reported that there was definitely more "muck" being discharged when flushing the system and less settling in filters, hydrocyclones and drippers. This irrigator is considering investing in more magnets.

Ozonation: Ozone has been used in water treatment in Europe and Asia since the late 1800s. It is a more effective disinfection agent than chlorine. It can also reduce iron and manganese concentrations by oxidising them to form insoluble metal oxides, which are then removed by filtration. Ozone is produced from oxygen, usually by passing dry, clean air through a high voltage electric discharge. The raw water is passed through a venturi throat which pulls the ozone gas into the water or the ozone is bubbled up through the water being treated. Oxyzone (www.oxyzone.com.au) is a supplier of ozone generation systems in Australia. The size of the system required depends on the iron concentration of the water being treated and the flow rate required. Indicative costs of an ozonation system have been estimated at $18,000 to $60,000. This company reports that it has supplied trailer-mounted ozonation systems to Sydney Water with excellent results.

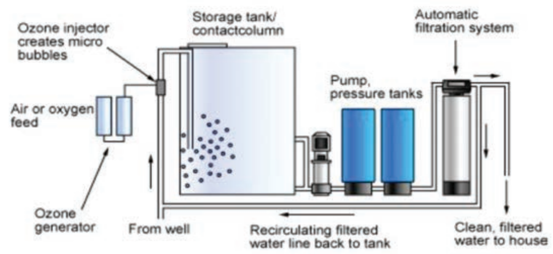


Diagram of an automatic ozone injection, filtration and recirculation system for iron and manganese.

Targeted Approaches

Targeted treatment approaches to iron bacteria problems are advocated by some specialists, e.g. Droycon Bioconcepts Inc. (DBI; http://www.dbi.ca/BARTs/FAQ.html). The reason for this is that there are many types of Iron Related Bacteria (IRBs) and the most effective approach in treating a clogging problem depends on the type of bacteria present. Specific testing can be carried out using the BART test system (see DBI website) to determine the composition of the bacterial community and this can then be used to design an effective treatment approach.

Recommended Best Management Practices for Iron Bacteria Problems in the Limestone Coast Region

Drilling New Wells:

1. Ensure that drilling equipment has been cleaned to minimize contamination.
2. Never put surface water down a well and do not use organic polymer muds in drilling wells or phosphorous containing mud breakers.
3. Avoid screening wells across hydrogeological units containing different water quality, particularly across low oxygen and high oxygen zones.
4. If possible, avoid screening wells across zones in the aquifer with high dissolved iron concentrations.
5. Test for water quality and iron bacteria on new wells (after evacuating 3 bore volumes).
6. If iron bacteria are identified in a new well, redevelop and shock chlorinate the well.
7. Develop wells thoroughly after drilling and always chlorinate after development.

Well Maintenance:

8. Chlorinate any equipment used on wells.
9. Never re-install any parts that are encrusted or covered in biofilm of any kind without thorough cleaning and chlorination.
10. When pumping water from low oxygen parts of an aquifer or containing high dissolved iron concentrations, avoid introducing oxygen into the pumped water, e.g. repair leaking seals and avoid mixing with water from near the water table.

Monitoring:

11. If your well is located in identified iron bacteria problem areas (i.e. Management Areas of Bool, Comaum, Glenroy, Joanna, Zone 5A, Zone 3A, Lucindale, Mayurra, Waterhouse, Wirrega and Tatiara), regularly test water (total and dissolved iron, iron bacteria) and monitor well performance. Any changes in water quality, iron bacteria numbers or well performance may indicate a developing iron bacteria problem and early detection is critical to effective treatment.

Treatment:

12. If clogging with a reddish-brown precipitate occurs, test the water and the clogging material as described above to determine whether the problem is bacterially mediated.
13. If the problem is confirmed to be iron bacteria related, implement an iron bacteria treatment program as soon as possible. Early intervention is critical to effective treatment.

Treatments for iron bacteria depend on the main location and severity of the problem. If iron bacteria are identified in the well, affecting well and pump performance:

14. Regular maintenance and servicing of pump may be sufficient. Chlorinate before re-installing. Monitor the severity of the problem and water quality, including iron bacteria numbers.
15. If the problem becomes worse, shock chlorination or regular chlorine dosing of the well may be required. Acid may be effective if the iron precipitate is not bacteria related or has a significant carbonate component.

If iron bacteria are mainly affecting irrigation distribution systems:

16. Chlorination, aeration or ozonation systems plus settling and filtration downstream of the pump may be required.

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Further Reading

The information provided above is summarized from the report:

Harrington, N.M. and Harrington, G.A. (2016). *Best Management Practices for Irrigation Water Quality Issues in the Limestone Coast Region of South Australia.* A report prepared for the Limestone Coast Grape and Wine Council and the South East Natural Resources Management Board by Innovative Groundwater Solutions Pty Ltd.

and readers are referred to that report for further information.
Further information can also be obtained from the Irrigation Water Quality Survey Report:

Harrington, N.M. and Harrington, G.A. (2016). *A Survey on the Irrigation Water Quality Issues Facing Irrigators in the Limestone Coast Region of South Australia.* A report prepared for the Limestone Coast Grape and Wine Council and the South East Natural Resources Management Board by Innovative Groundwater Solutions Pty Ltd.

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