New Zealand
Farm Environment Trust®

John and Catherine Ford

2015

Winners of the Gordon Stephenson Trophy

and

National Ballance Farm Environment Award.

Ministry for Primary Industries
Manatū Ahu Matua

During our tenure as holders of the Gordon Stephenson Trophy, Catherine and I were invited to do a number of presentations about our farming operation around the country and also had various groups visit and tour Highlands Station. Near the end of our year we went on an overseas study trip to the USA.

Presentations:

We gave a total of 21 presentations to date, to a diverse range of groups that included organisations such as, the Government Primary Sector Select Committee in Wellington, the Red Meat Sector Conference in Nelson, Grasslands Hill-Country Symposium in Rotorua, but also smaller meetings like Rotorua Probus.

Key points covered in our presentations were:

1. Highlands Station has been farmed by the Ford family for 85 years.
2. We are supported by a great team who are involved in all aspects of farm management.
3. Our involvement in farm discussion groups has given us inspiration and advice, and has been the key component in our success.
4. Highlands Station's production and profitability is very high for a hill-country sheep and cattle property, yet by running stock policies that sustainably match the class of farmland and grass growth, with minimal cropping and no supplements, the farm has a low environmental footprint.
5. Approximately 25% of the property is retired native bush, some 143 ha of which is in the QE II National Trust.
6. Substantial stream retirement has been completed.
7. Over 230 dams/silt traps have been built to reduce erosion and nutrient loss.
8. The management philosophy is to ensure that the potential of the people, stock, and land is realised in a sustainable way, so that they can still be farming in 100 years, or more, through a policy of continual improvement.
9. One of their favourite phrases is: "You have to be in the black to be green, but to be in the black long-term, you must also be green long-term."

Colin James, John Ford, Bryce Johnson, and Phil Mackenzie, at the 2015 Red Meat Sector Conference in Nelson.

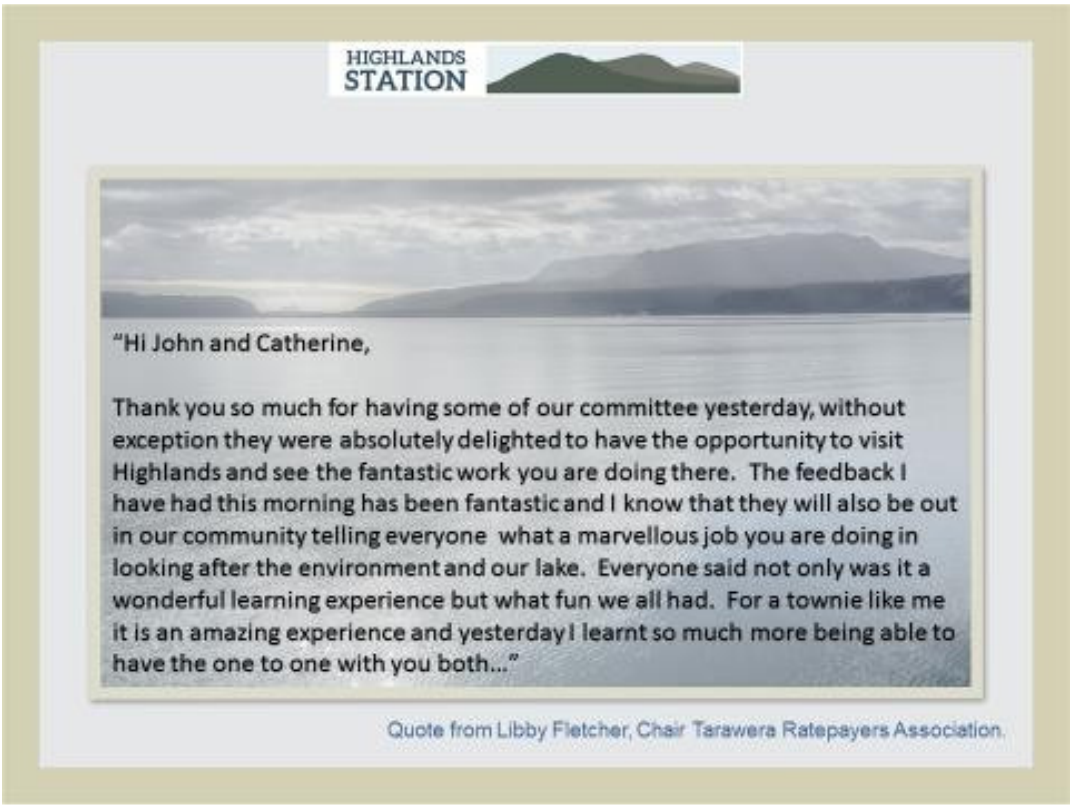
Farm Visits.

Our primary purpose in entering the awards was to gain credibility with the Bay of Plenty Regional Council and the Lake Tarawera community in relation to any impending rules and regulations that might be placed over our catchment and our farm. We achieved this goal with our regional win and this was reinforced with our national win.

We had our field day on the property as BOP Regional winners on March 31st 2015, and were very pleased that Doug Leader, Chair of the BOP Regional Council, as well as 5 council staff attended. Libby Fletcher Chair of the Lake Tarawera Ratepayers Association also attended with fellow Lake Tarawera friends. Since that field day a total of 8 groups have also visited Highlands Station and include groups that range from a group of about 20 ANZ Bank's Rural Managers in a day facilitated by our farm consultant Will Wilson, to a bus load of school students from the St Pauls Collegiate Agribusiness class.

However the highlight of our term as National BFEA winners would be our association with Libby Fletcher and her committee from the Lake Tarawera Ratepayers. Libby came to Catherine and me at the end of our field day in March to say that she had had a wonderful day and that her assumptions about farmers had been turned on their head. She was very impressed and pleased to see what we were doing both as farmers and for the environment in the Lake Tarawera catchment.

Libby then arranged to bring her committee back to the farm in October for a tour and we were also able to show them the power point presentation we had made for one of our Beef + Lamb New Zealand speaking engagements. Libby sent a very nice email after our day that I have quoted in a number of subsequent presentations.



In March this year we had another field day organised by the BOP Regional Council where Catherine and I met with other attendees at the Council office in Rotorua. The group included the whole range of people interested in the future health of Lake Tarawera including residents, Lakescare Society members, Maori owners of the lake, mountain and farmland, other farmers in the inner and outer catchment, Professor David Hamilton lake scientist, and BOP Regional Council staff.

From Rotorua city we were bussed out to Lake Tarawera and then had a launch trip around the lake, with talks by the residents about the history, science, and current state and future of the lake. We then bussed from the lake to the farm looking at both our farming operation and the environmental works such as dams, bush retirement blocks etc. We finished with some short talks by other farmers in the catchment.

The day was an excellent method of informing all the interested parties about everything in, and around the lake. One of the day's best quotes was that; "*a picture might be worth a thousand words, but seeing something for yourself was worth a million words."* The day we all spent together enabled everyone a chance to talk and understand each other's point of view, based on what they could see and hear themselves without relying on third party reports or often misguided assumptions. This day will hopefully be remembered as a turning point towards a more collaborative approach between all stakeholders developing a mutually acceptable Restoration Plan for Lake Tarawera, rather than the misunderstanding, acrimony and lawsuits that plans elsewhere have sometimes resulted in.

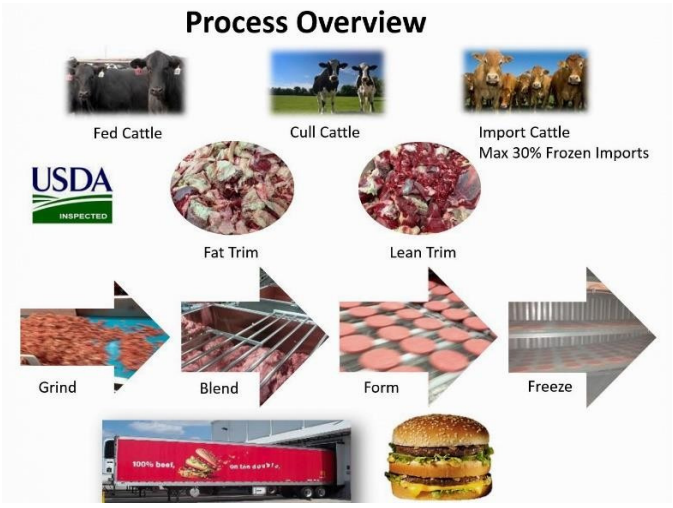
To quote Peter Senge, Systems Scientist. "*Extraordinary change requires building extraordinary relationships, and at some level this requires gathering together diverse people representing diverse views so they can speak and listen to one another in new ways."*

Study Trip.

On April 23rd 2016 Catherine and I left for a three week study trip in the USA. We wanted to see what McDonalds did with our bull beef, and what farmers were doing to improve water quality around Chesapeake Bay.

<u>Fresno, California.</u>

We went to the McDonalds plant in Fresno that was built adjoining a beef plant owned by Cargill Ltd. The McDonalds plant processes 160 ton of meat into hamburger patties each day, which equates to approximately 1 billion patties a year. Thirty percent of the meat used is frozen "95% lean" meat imported from New Zealand and Australia, and we saw cartons of Riverlands and Silver Fern Farm meat being used while we were there. Our frozen meat is blended with the higher fat percentage meat sourced from the adjoining Cargill plant to make the "perfect" McDonalds meat pattie.



While in Fresno we also visited Maddox Dairy an intensive housed dairy farm milking over 3,500 cows 3 times daily, and had a day trip to Yosemite National Park which was absolutely beautiful.

Washington City, Maryland and Virginia.

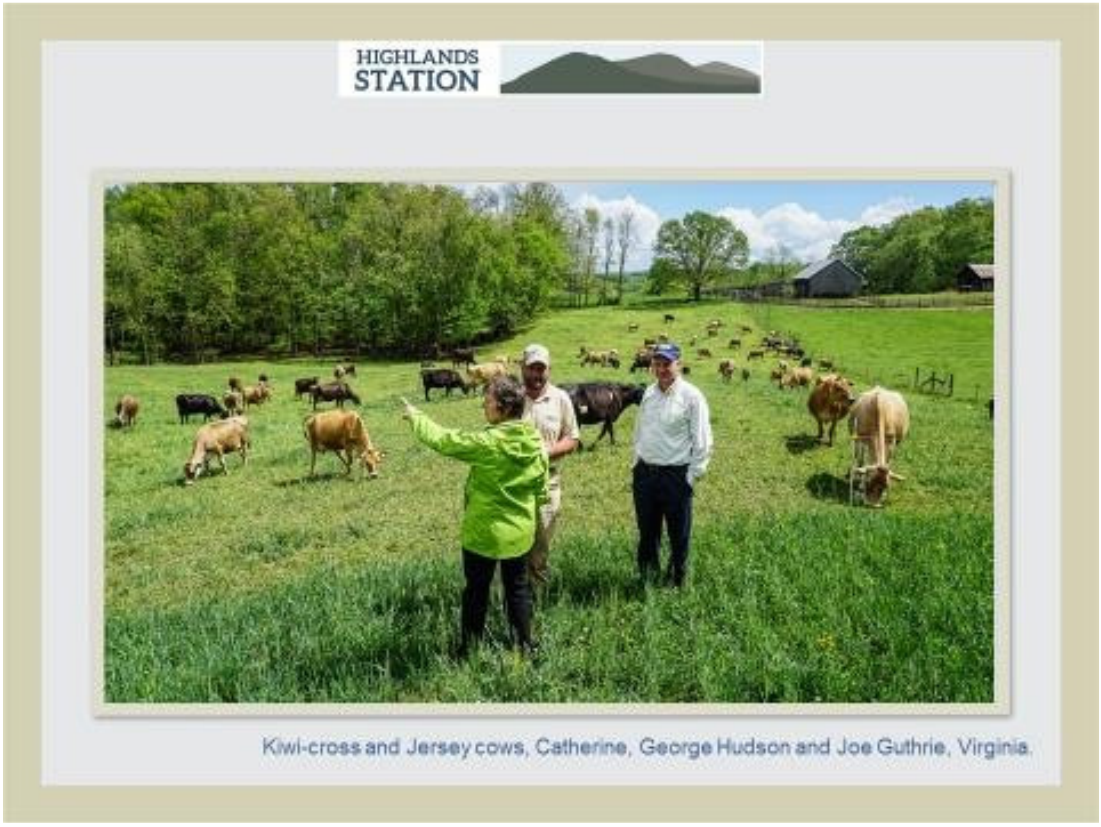
We were primarily escorted around Maryland and Virginia by Beef + Lamb New Zealand's North American Manager Terry Meikle, and also by Joe Guthrie of Virginia Tech University. We visited a number of research organisations and farms. Key observations we had were:

1. The absolutely huge level of subsidisation by the government for any environmental work that is done on farms.
2. Farmer's attitude was to only do environmental work if it was subsidised. When we told them how much work NZ farmers did without subsidies they were impressed, but also thought we were absolutely crazy to do it without government assistance.
3. Farmers that had done some environmental work which they called BMP, (Best Management Practices), such as cover crops, fencing streams, riparian planting, or bio reactors, did so with an agreed Farm Environment Plan with agency they were dealing with. None of these plans were imposed on landowners, they were all agreed to between farmer and agency, and as a result both parties showed a strong commitment to the plan. This was an important difference between our situation in NZ where the imposition of rules is prompting some landowners into confrontation with councils rather than the genuine collaboration we saw in the USA. Of course the subsidies help immensely with the attitude difference! But it also reflects the key difference in our societies where the USA value personal freedom above fairness and NZ the reverse. (suggested reading "Fairness and Freedom, the story of two open societies New Zealand and the United States by David Hackett Fischer)

4. Subsidies for environmental work were usually seven eighths of the cost or 87.5%.

5. Most of the farms we visited only had short term, maximum of 15 years security, if any, for any subsidies received. Whereas here in the Bay Of Plenty any subsidy, if available, is secured for 999 years.

6. Compared to NZ, the USA has an extremely complicated political system with the extra levels of government, from local, County, State, and Federal political bodies, plus NGO's (Non-Government Organisations). This level of complication and the sheer size of these organisations will make any change to their agricultural, environmental, and subsidy policies very slow.
7. Chesapeake Bay is approximately three quarters of the area of NZ, but has 18 million people, governed by six states; New York, Virginia, Maryland, Delaware, Pennsylvania, and West Virginia.
8. We met with only one farmer who ran his dairy farm in a similar way to NZ, and his primary reason for doing so was to avoid the cost, of buildings machinery and labour, and therefore financial risk, that an indoor system of housed cows and a cut and carry system entailed. He said his profit for his 250 cow farm was still good.



Kiwi-cross and Jersey cows, Catherine, George Hudson and Joe Guthrie, Virginia.

9. Where we went most farms were arable and the nutrient pollution was from too much litter and manure from chicken and turkey farms being spread on the land.
10. I have attached in the appendix, an article by T.J. Kirkpatrick for Politico Magazine that gives an excellent overview of the farming/environment and political situation for Chesapeake.

11. The most interesting research we saw that could have applications in New Zealand was for bio-reactors, by Dr Tom Fisher and Tim Rosen. Bio-reactors can reduce nitrates in water by as much as 90% and phosphates 75%, and an email I have sent out on these is also attached in the appendix. An excellent video on bioreactors is also available at: https://www.youtube.com/watch?v=DxGkdFQOPII

12. After Chesapeake we went to New York City and visited Rabobank and met with Tom Bailey head of research for dairy products. Among the many things we discussed was the unrealised potential of our produce. He showed us a photo of cheese at his local super market where NZ cheese was being sold. There were a whole range of cheeses and brands on display and of them all the NZ cheese probably had the best story, i.e.: grass-fed, living outside in a natural environment, no subsidies, no cheap labour etc.… and yet it was the NZ cheese being discounted. New Zealand and our exporters can do a lot better.

13. While the USA has a strange political system and way of doing things compared to us, all the people we met were very generous with their time, interested in us and visa versa.

Catherine and Joe Guthrie, Virginia Tech, Blacksburg, Virginia.

My presentation to Virginia Tech, Blacksburg, Virginia

The Last Word

Writing this report is our last official function as 2015 BFEA winners and we would like to take the opportunity to answer two questions we have been most frequently asked over the last year, which are:

- How have you managed to have such a productive and profitable farm, yet also have such a low environmental footprint?
- And then given our government's desire to double NZ's export earnings by 2025, and also to improve our country's water and environment, h ow can other farmers be helped to achieve similar results to yours?

The answer to the first question about how we have achieved our results is simple; we have over the years received a huge amount of inspiration and advice from people, especially our farm discussion group, my family, many various consultants, our staff, and other farmers. They have inspired us to be the best we can be, and helped with advice on how to do that.

The answer to the second question is almost the same, while farmers are a varied lot, one thing is common and that is a desire to run a good farm and look after their land. However most have not had our luck with meeting the people advising or inspiring them or the confidence to change. Looking back the start of our development was in the 1980's when I was invited along to a farm discussion group facilitated by a MAF consultant Peter Livingston. Since then our involvement in discussion groups, and the various consultants that have facilitated them, has been the basis of all our improvement as farm managers and in developing our farm business.

New Zealand agriculture is being challenged to now improve production and reduce our environmental impact. Perhaps the regulations and farm environmental plans we are being required to meet, are also the opportunity to encourage farmers to review their thinking and systems, and our experience is that the best way to do this is with discussion groups and good farm consultants. While we pay the full costs of consultants now, I do not recall having to do so originally when we started in the 1980's and that low cost was a factor in joining the group initially.

Resurrecting a low cost service to farmers through something similar to the old MAF model, which was also a very valuable training ground for graduates to become consultants, of which there is a shortage, to provide advice and facilitate farm business discussion groups, would be of real assistance to helping farmers adjust to the changes required by Regional Councils, and improve their farm management and performance. This is a wonderful opportunity for government to provide leadership and guidance, for agriculture and the nation, towards both an improvement in agricultural export earnings and a better environment. Food for thought!

John and Catherine Ford.

Acknowledgements:

We would like to thank all those who have assisted us over the last eighteen months, especially our team here on Highlands Station when Catherine and I have been away: George Bulled, Daniel Hodson, Bronwyn Edwards, Colin Mead, Kevin Kelly, and Richard French. Thank you to our fellow discussion group members for their advice and encouragement over the years and for pushing us into entering these awards. We have received huge support from all those involved in the Ballance Farm Environment Awards, especially the sponsors who are making a very real difference to NZ agriculture through these awards. In the USA we met many people who gave us their time, ideas and insights which made the tour so interesting and enjoyable. Thank you especially to Terry Meikle, Joe Guthrie, and Joanna Ogburn. Thank you all for sharing your time, your stories and your love of farming and the land, with us.

Appendix includes:

1. BFEA fact sheet about our property, http://www.nzfeatrust.org.nz/vdb/document/315
2. Email from us about bio-reactors.
3. Study trip itinerary.
4. Copy Document. Bio-reactors information sheet from Virginia Tech. Also at: https://pubs.ext.vt.edu/BSE/BSE-55/BSE-55-PDF.pdf
5. Copy Article by Annie Snider for Politico Magazine on Chesapeake Bay. At: http://www.politico.com/agenda/story/2016/05/obama-chesapeake-bay-restoration-000127

Suggested reading:

Fairness and Freedom, the History of Two Open Societies, New Zealand and the United States, by David Hackett Fischer. Pub. 2012. https://www.bookdepository.com/Fairness-Freedom-David-Hackett-Fischer/9780199832705

Links:

- BFEA Video of Highlands Station: http://www.nzfeatrust.org.nz/sustainability_in_action_dvds/id/696
- Bio-reactors video: https://www.youtube.com/watch?v=DxGkdFQOPlI

Appendix:

(1) BFEA handout for Highlands Station

Ballance Farm Environment Awards®
Promoting Sustainable Profitable Farming

BAY OF PLENTY

2015 SUPREME AWARD WINNERS

ALSO WINNERS OF:
Ballance Agri-Nutrients Soil Management Award
Beef + Lamb New Zealand Livestock Award

"DAD BEGAN BY GRAZING PART OF THE LAND IN 1931 AND IN 1932 PAID £800 FOR ABOUT 2500 ACRES AS A BALLOT BLOCK."

John and Catherine Ford – Highlands Station

Volcanic action "cleared" much of the forest, shaped the land and continues to influence how Highlands Station near Rotorua is farmed.

Today, John and Catherine Ford and their farming team of Daniel Hodson, Bronwyn Edwards, Kevin Kelly, Colin Mead and George Bulled farm the land, but it was John's father Allen who began its development in 1931.

"Dad began by grazing part of the land in 1931 and in 1932 paid £800 for about 2500 acres as a ballot block," says John.

The Tarawera eruption of 1886 had flattened much of the bush. When Allen bought the farm most of it was covered in fern and scrub, which he burnt, cleared and gradually turned into pasture. Even today holes left by rotting tree stumps are a hazard for stock, dogs and farm staff.

"We once employed a college student, who spent all his August holidays filling up holes in just one paddock," says John.

The eruption also coated the hills with ash, and heavy rains which followed created distinctive "rills" like large vertical corrugations, down the faces of the hills.

Allen left most of the surviving bush standing but extracted rimu, using bullocks, to pay for farm development.

Today 320 hectares of bush are protected under QEII National Trust, regional council and private covenants and 18km of fencing has been constructed to keep stock out.

The Mount Tarawera eruption may have had the most dramatic and recent impact on the land, but its volcanic history goes back much further.

Rotomahana mud is up to two metres deep in places. The Kaharoa ash is drier but lacking in minerals, and underneath is Taupo pumice.

Continued over page >

QUICK FACTS

Type of Farm	Sheep and Beef
Location	Rotorua
Topography	Hill country
Total/ Farm Area	1240ha
Commenced	1931

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BAY OF PLENTY

2015 SUPREME AWARD WINNERS

HIGHLAND STATION'S MEAT AND WOOL PRODUCTION PUT IT AMONG THE TOP FIVE PER CENT OF NEW ZEALAND DRYSTOCK FARMS. DESPITE ITS STEEP NATURE, THERE'S NO EROSION ON THE HILLS THANKS TO CAREFUL GRAZING MANAGEMENT.

Highlands Station stands on an old rhyolite dome formed about 250,000 years ago and John can read its history in layers exposed in farm track cuttings.

Continued from previous page >

The mud soils are high in phosphate and to reduce phosphate loss John has constructed up to 200 detention dams throughout the farm, which slow the run-off and collect sediments.

On August 20, 2014, the dams were thoroughly tested by the biggest rainfall in 10 years. They held the water in the upper catchments and in places no water flowed out, showing how effective the dams are in retaining water and reducing sediment loss.

The farm is in the catchments of Lakes Tarawera and Rotokakahi (Green Lake). Catherine and John, who purchased the farm from John's siblings in 1995, take this into account within their farm management practices.

This has included a move away from cows to raising beef bulls and steers, and breeding ewes.

Properly managed, says John, the bulls have less impact on the land and nitrogen leaching. The young stock arrives in November and is sold after 15 months.

Many farmers are turning away from raising bulls to taking on dairy grazers because bulls are perceived as hard work. "However, if you manage them and understand their nature, they're not; and the financial rewards are greater."

Highlands Station bulls – Catherine likens to unruly teenagers – are managed by keeping them in relatively small groups, giving them room to get away from each other and feeding them well.

Sheep perform well at Highlands Station too. Romney genetics have been introduced to improve facial eczema resistance and robustness.

No supplements are fed out or made on-farm. Stock numbers are carefully linked to the available pasture and John doesn't hesitate to reduce numbers if a drought is looming.

Highland Station's meat and wool production put it among the top five per cent of New Zealand drystock farms.

Despite its steep nature, there's no erosion on the hills thanks to careful grazing management.

In all, the farm covers 1240ha, of which 992ha are effective. Managing a property of this size takes planning and requires good infrastructure.

This includes 17km of tracks to maintain strategically placed yards, the use of solar-powered electric fencing in remote parts of the farm and a water wheel which pumps water to tanks from where it is gravity fed to troughs.

The Highlands Station staff are actively involved in the farm's management and decision-making with each responsible for a different part of the farm and mobs of stock, creating a healthy competition to reach target growth rates.

"The success of Highlands Station is due to our staff," says Catherine. "We are the owners and take the financial risk but our staff produce the results which make it viable.

"At least the last 10 per cent or more of stock production and performance comes from staff decisions and knowledge."

JUDGES' COMMENTS

- Strong family history of commitment to agriculture
- Excellent understanding of water dynamics, both above and below the ground
- Effective and outstanding staff management programme
- Appropriate use and management of land, based on its capabilities and catchment.

(2) Email concerning bio-reactors

Hello All,

Please excuse the impersonal email but I am sending this to as many people as might be interested as possible, and hope that you may also forward this to anyone else you think may be interested.

Catherine and I recently returned from our study trip to the USA that we won as recipients of the Gordon Stephenson Trophy and National winners of the Ballance Farm Environment Awards. One of the research projects we saw in Virginia impressed us as having considerable potential here in New Zealand as a means of reducing Nitrogen and Phosphate in water by as much as 90% of N, and 75% of P, in a practical and relatively cheap way.

Dr Tom Fisher from the University of Maryland Center for Environmental Science and Mr Tim Rosen a watershed scientist with the Midshore Riverkeeper Conservancy, showed us a trial they were running with a denitrifying bio-reactor. The bio-reactor was essentially a large pile of airtight wood shavings through which high nutrient loaded water passes. The anaerobic bacteria within convert up to 90% of the nitrates in the water into inert N2 gas which eventually disperses to the atmosphere, and most of the phosphate is absorbed by the bioreactor. The attached pdf file from Virginia Tech gives more detail, and there is a good short video covering bioreactors at: https://www.youtube.com/watch?v=DxGkdFQOPlI

The project we saw was next to an arable field where a hard subsurface pan meant most of the ground water drained through tile and mole drains into a ditch and the ditch water was then passed through the bio-reactor, with automatic sampling machines at both intake and outlet to enable the effectiveness of the bio-reactor to be measured. The photo below shows the bioreactor intake, and intake auto sampler, the bio reactor itself is sealed and buried beneath the people standing, and in the far distance the outlet auto sampler can be seen. The bioreactor was approx. 18 long by 10 wide and 1.5 metres deep full of wood shavings and then sealed over with soil and sown in grass. (NB the black structure on the left is a deer hunting hide!)

The next photo shows some of the detail of the auto samplers, and Dr Tom Fisher, Joanna Ogburn an Advisor for the Chesapeake Conservancy, and Catherine Ford.

The situation this bio-reactor was set up in, where most of the ground water is draining out through ditches is quite different to our soil conditions here in Rotorua, but may be similar to other areas in New Zealand like parts of the Waikato for example. I could also see considerable potential for a bio-reactor being used to treat nutrient loaded water from septic tanks, stock effluent ponds, or as an alternative or addition to constructed wetlands.

The fact that a bio-reactor can be easily made from readily available natural materials, and has already had considerable research science completed on their effectiveness in the USA, has lead me to believe they also have considerable potential here in New Zealand. My hope is that someone who receives this email will agree with me about the potential of bio-reactors and have a site, and funding where a bioreactor could be set up, and tested, so as to gain credibility, publicity and acceptance, as a mitigation tool in our battle to reduce nutrients in our waterways. Please pass this on to anyone you think may be interested, or who may be able to publicize this invention.

We would also acknowledge and thank:

The Ballance Farm Environment Award Trust and sponsors and especially; David Natzke General Manager of the BFEA, Terry Meikle Regional Manager for Beef and Lamb in North America, and Joanna Ogburn of the Chesapeake Conservancy, who all played a part in organising our trip around Virginia and Maryland. A special thanks to Dr Tom Fisher and Tim Rossen for showing us their bio-reactor project. Thank you.

Regards,

John and Catherine Ford.

Highlands Station, RD 3 , Rotorua 3073. jgcmford@farmside.co.nz

0272941876 or 07 3478767

(3) Study Trip Itinerary

John and Catherine Ford – draft visit programme (Wednesday 27 April – Wednesday 4 May)

Wednesday 27 April

- Arrive into Washington Dulles (late afternoon)
- Taxi to accommodation in Annapolis
- Book one night in Historic Inns of Annapolis, State Circle.

Thursday 28 April

8am: breakfast in hotel

8.45am: Terry picks up from hotel

9am: Chesapeake Bay overview meeting with Kelly Shenk, Agricultural Advisor, EPA Chesapeake Bay Program Office, 410 Severn Avenue, Suite 112, Annapolis, MD 21403

10am – depart for Chesapeake Bay Heritage Center

10.30am – 11.30am Chesapeake Bay Heritage Center (learn about the agricultural, maritime and environmental legacy of the Eastern Shore)

11.30am – depart Chesapeake Bay Heritage Center for Wye Research Center

12pm – 2.30pm: Wye Research Center (Nancy Nunn): meeting with Board members, address the PMT among other issues. Lunch. Farm visit on-site (time permitting). Kelly Shenk and Joanna Ogburn to join.

2.30pm: depart Wye Research Center for Talbot County ditch project. Joanna Ogburn and Kelly Shenk to join.

3pm – 4pm: Talbot County ditch project. Location TBC (Amy Jacobs with The Nature Conservancy and Alan Girard with the Chesapeake Bay Foundation)

4pm: drive to St Michaels, MD.

Book one night in Point Breeze B&B - http://www.pointbreezebandb.com/about.shtml I will stay at this B&B as well.

Friday 29 April

8.30am: breakfast in hotel

9.30am: depart for 13989 Century Farm Rd. Greenwood, DE. Forestry conservation success story - NRCS CREP project on display. The owner of the property has spent quite a bit of time in New Zealand and some of the grasses he has used on his property were developed in New Zealand. Wear a bug spray at this property as there may be some ticks out. He's going to recommend a spray for folks to use on their clothing.

12.30pm: lunch details (TBC)

1.30pm: Depart for farm illustrating the installation of BMP's (location TBC).

2pm-3.30pm: BMP farm

3.30pm: Drive back to Washington DC.

Book two night's accommodation in The Churchill Hotel, 1914 Connecticut Avenue NW

Saturday 30 April

All day: own plans in Washington DC

Sunday 1 May

Morning: own plans in Washington DC

2pm: Terry to pick up from hotel.

Depart for Orange, VA

Book one night's accommodation in Holiday Inn Express Orange, 750 Roundhill Road, Orange, VA 22960

Monday 2 May

Morning: Farm visits in Shenandoah Valley – Orange (Steve Hopkins), New River Valley (Jason Carter from Virginia Cattlemen) and time permitting Roanoke (water quality focus).

Late afternoon: drive to Blacksburg

Book one night's accommodation in Clay Corner Inn 401 Clay Street SW, Blacksburg, VA 24060

Tuesday 3 May

Morning: free to explore Blacksburg and Virginia Tech campus.

11.30am: Joe Guthrie to pick up from hotel

Midday: Virginia Tech seminar presentation

2pm: farm visit with Joe Guthrie

4pm: Joe Guthrie to drop you at Charlotte hotel near airport for flight the following morning to NYC.

Book one night's accommodation at Hyatt Place Charlotte Airport, 2950 Oak Lake Blvd, Charlotte, NC 28208

Wednesday 4 May

Depart Charlotte, NC for NYC.

VIrgInIa CooperatIve ExtensIon

PUBLICATION BSE-55P

Denitrifying Bioreactors: An Emerging Best Management Practice to Improve Water Quality

Emily Lassiter, Graduate Research Assistant, Biological Systems Engineering, Virginia Tech
Zachary M. Easton, Assistant Professor and Extension Specialist, Biological Systems Engineering, Virginia Tech.*

What is a Denitrifying Bioreactor?

Denitrifying bioreactors (DNBRs) are an alternative best management practice (BMP) that can reduce the amount of nitrogen reaching surface waters. DNBRs function by supporting soil microorganisms that are capable of *denitrification*** in a favorable environment (see Figure 1). Denitrification is the process by which microorganisms transform *reactive nitrogen*** in the form of nitrate-nitrogen (NO_3-) into nitrogen gas (N_2). Denitrifiers are *heterotrophic microbes*** found in most soil that utilize energy from organic carbon sources to transform NO_3- to N_2 in the absence of oxygen. These anaerobic (meaning without oxygen) conditions are created when soils become saturated with water. Fundamentally, DNBRs consist of an organic carbon medium that is saturated, at least periodically, with sufficient duration to allow anaerobic conditions to develop and naturally occurring denitrifiers to flourish.

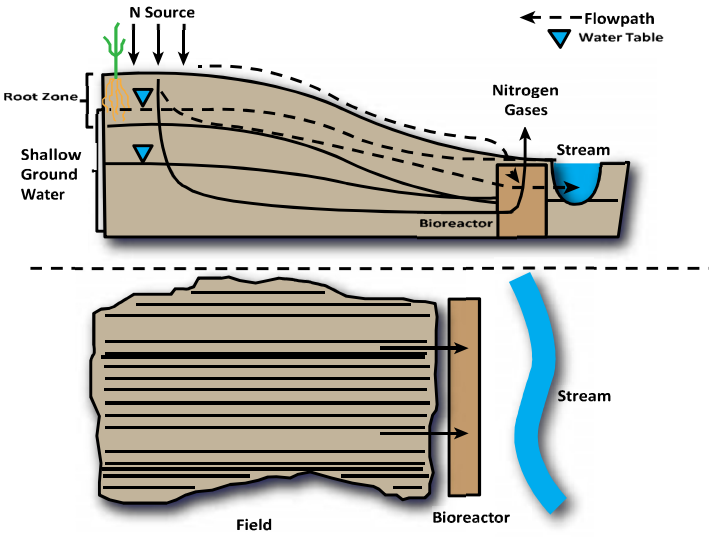


Figure 1. The top figure shows an example of a DNBR

**Terms defined in the glossary at the end of this publication are italicized the first time they appear in the text.

www.ext.vt.edu

Produced by Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, 2013

Problem: Water Quality

NO_3- moves easily with water through the soil profile. When shallow groundwater intersects the plant rootzone where nutrients are present; NO_3- can *leach*** from the rootzone, and phosphorus (P) can be a water quality concern at very low concentrations although it is not considered highly mobile in the soil. One way to minimize NO_3- and P loss is to effectively manage the amount of fertilizer applied to a crop by actively following a nutrient management plan (NMP). Even with active fertilizer management, NO_3- and P can be lost when shallow groundwater intersects the rootzone

* Corresponding author email: zeaston@vt.edu

(see Figure 1). This risk is particularly high during periods of prolonged or excessive rainfall, which can cause a rise in the shallow water table whereby it can intersect with the rootzone where nutrient levels can be high and ultimately cause leaching (see Figure 1). Thus, alternative edge-of-field technologies are needed that can remove nutrients from shallow groundwater and runoff. DNBRs, an emerging technology, hold promise to treat both excess N and P in ground and surface water.

placed strategically in the landscape to intercept and treat ground and surface water before entering the stream. The dashed line shows how the groundwater table might respond to precipitation, rising to intersect with the rootzone and mobilizing nutrients. The bottom figure shows a plan view of a DNBR as it might be installed adjacent to a field.

Denitrification is important because it is the only permanent removal of *bioavailable*** nitrogen from an ecosystem. Even relatively low N concentrations in receiving water bodies can cause *eutrophication*** and damage fisheries. The U.S. Environmental Protection Agency (EPA) recommends that the maximum stream nitrate-N concentration be less than 0.3 parts per million (ppm) for the Coastal Plain region. Higher levels of NO_3-, particularly in drinking water, can lead to infant toxicity (methemglobinemia or Blue Baby Syndrome) or formation of carcinogenic compounds. The EPA has set a *maximum contaminant*

*level (MCL)*** for nitrateN in drinking water at 10 ppm.

Applications

DNBRs have been used to treat a range of nitrateladen waters including greenhouse effluent, contaminated groundwater, septic system plumes, domestic wastewater, and agricultural runoff. Common designs include walls intercepting shallow groundwater (as in Figures 1 and 2), reactor vessels that receive tile drainage from agricultural fields, beds where the influent is piped in, and streambed bioreactors. The different designs are adapted and employed in the various settings. Many types of organic carbon have been tested for use in DNBRs,
but woodchips are the most widely used because of their superior hydraulic properties and general availability in larger quantities.

Research has shown that successful nitrogen removal can be obtained in these *field scale*** systems for up to 15 years even with fluctuating influent nitrate concentrations and flow rates. This tolerance to variable influent enables application of DNBRs to treat a wide range of *non-point source pollution*,** such as that created by agriculture, where conventional wastewater treatment is cost-prohibitive. Some of the greatest potential for DNBR use is in agricultural settings, where nitrogen loss to groundwater is the dominant pathway.

Current Research

The denitrification wall DNBR receiving shallow groundwater and surface runoff from agricultural land at the Eastern Shore AREC, as shown in Figure 2, has been monitored since August 2011. The DNBR consists of two separate compartments with two types of carbon media: woodchips only and woodchips with biochar. The addition of the biochar, a form of organic carbon produced by burning organic material, is a novel media in DNBR research and holds promise for increasing

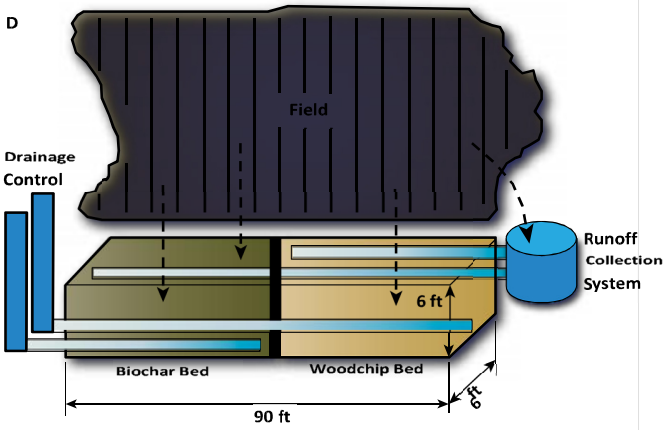


Figure 2. Design and application of the Eastern Shore Agricultural Research and Extension Center (AREC) "wall" type DNBR. Image A shows excavation of DNBR trench; B shows wood chip substrate in the DNBR; C shows addition of *biochar*,** and D a schematic of the design. The two treatments have separate outlets with drainage control. The upslope sides of each DNBR are lined with permeable filter fabric to allow shallow groundwater to enter. The volume of the two DNBRs together is approximately 100 m^3 and it receives drainage from 12 acres of cropped farmland.

NO_3- and P removal. Previous studies have shown that biochar increases microbial activity, which may enhance the rate of denitrification, and reduce nitrogen leaching. Biochar also has the potential to remove P in groundwater by *adsorption.***

The data displayed in Figure 3 show that the DNBR achieved significant nitrate reductions in groundwater. Nitrate concentrations were, on average 60 percent (and as high as 90 percent) lower

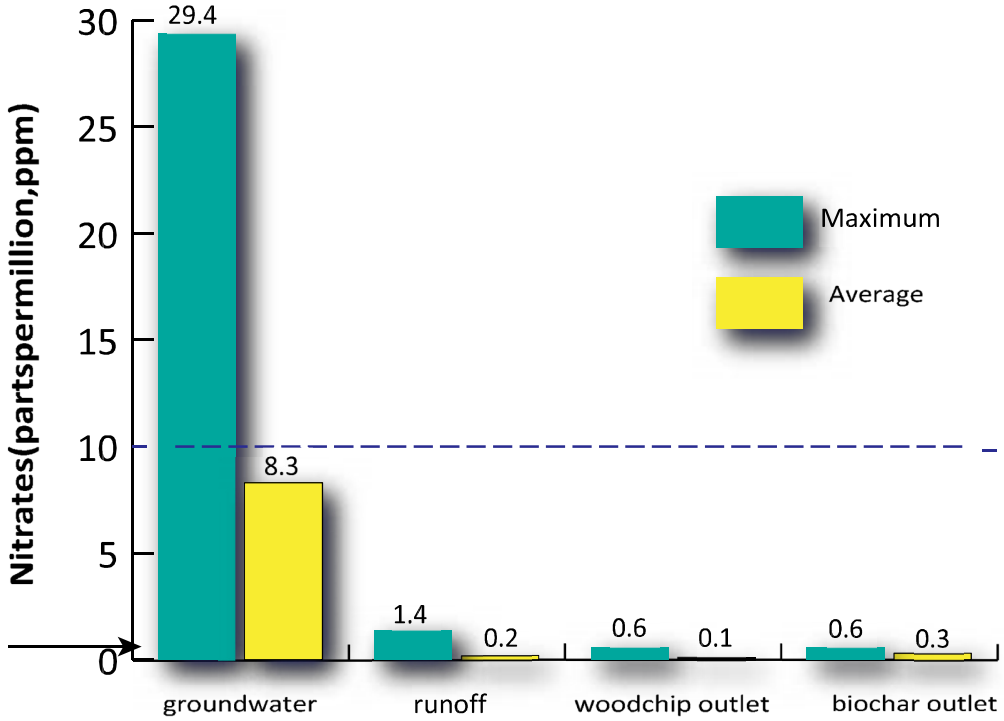
in groundwater that had passed though the DNBR than in the groundwater draining from the contributing fields. Groundwater samples were collected from six wells located in the 12 acres of agricultural land draining to the DNBR. The maximum nitrate-N concentration observed in the groundwater is almost 30 ppm, or three times the EPA MCL limit for drinking water, and more than 100 times the levels recommended for stream health. The average nitrate-N concentration observed in the groundwater approaches the 10 ppm drinking water MCL. This specific DNBR includes a runoff collection and dosing system (see Figure 2) to allow treatment of surface runoff in addition to groundwater. The runoff well collected overland flow from the 12 acre contributing area of the farm. Drainage control units (Figure 2) allow for water table control in order to achieve adequate residence time for denitrification to occur as well as for sampling the outflow.

Both the woodchip and biochar beds performed well, and both carbon source materials achieved the same maximum level of nitrate reduction. On average, both substrate treatments in the DNBR were able to reduce nitrate-N to the 0.3 ppm level recommended by the EPA as the maximum concentration to maintain stream health in the Coastal Plain region (Figure 3).

These results indicate that DNBR implementation in strategic locations intercepting shallow groundwater and/or runoff has the potential to provide NO_3-removal levels on site that translate into measureable downstream water quality improvement.

The DNBR also reduced the dissolved phosphorus concentrations as shown in Figure 4. Note that all phosphorus concentrations observed in the groundwater in this study were higher than the 0.04 ppm level recommended by the EPA as the maximum concentration to maintain stream health in the Coastal Plain region. Although phosphorus does not have direct toxic effects in humans, excess can stimulate the growth of microorganisms undesirable in potable water.

Both DNBRs were able to significantly reduce P concentrations in groundwater. The biochar addition substantially increased phosphorus removal as compared to the woodchips alone. The outlet concentration from the biochar treatment approaches the 0.04 ppm maximum recommended level set by the EPA for stream health in this region. DNBRs with biochar amendment have the potential to consistently reduce dissolved phosphorus concentrations by 75 percent or more.



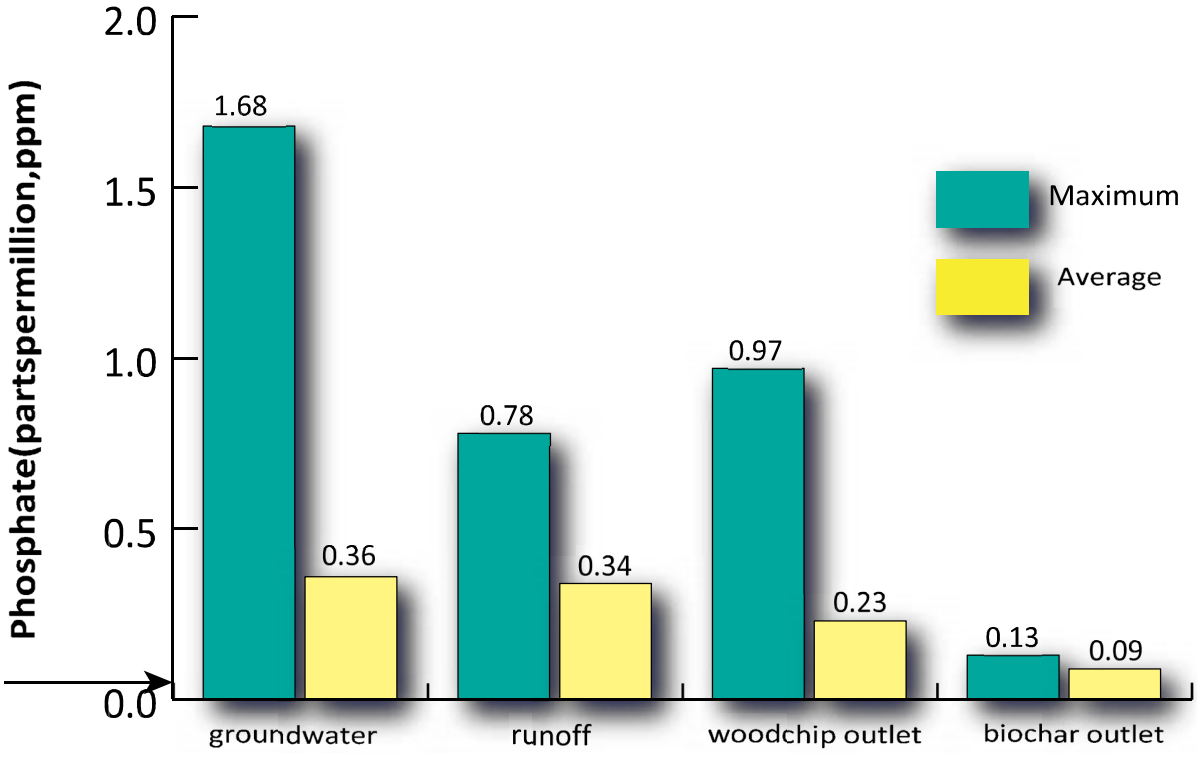


Figure 3. Maximum and average concentrations of nitrate-N (ppm) measured in water samples collected from groundwater wells and the DNBR between January and May 2012. The dotted black line indicates the EPA MCL for nitrate- N in drinking water (10 ppm). The arrow indicates the EPA recommended maximum concentration for stream health (0.3 ppm)

Figure 4. Maximum and average concentrations of phosphorus (ppm) measured in water samples collected from groundwater wells between January and May 2012. The arrow indicates the EPA recommended maximum concentration

for stream health (0.04 ppm)

Cost

DNBRs are inexpensive to install and generally maintenance-free. For instance, the DNBRs located at the Virginia Tech Eastern Shore AREC cost less than $200 per acre treated. If this is extended out over the expected lifetime of the system (15-20 years), the cost of the DNBR system approaches $10-15 per acre per year. This is comparable to, or less than, other water quality BMPs such as riparian buffers, exclusionary fencing, or nutrient management planning. The only costs are incurred at installation, which include excavation and the purchase of substrates such as woodchips and biochar. If DNBRs prove to be a valuable BMP, cost share dollars from federal (such as the U.S. Department of Agriculture-Natural Resources Conservation Services (USDA-NRCS)) or state and local (such as Soil and Water Conservation Districts) sources might offset much of the initial cost.

Future Work

Continued study of the Eastern Shore AREC DNBR and other installations in Virginia will focus on monitoring inlet an outlet nitrate-N concentrations in real time in order to develop a nitrogen balance, which will allow for quantification of nitrate removal and assessment of downstream water quality benefits. This work will provide data that can be used to develop DNBR engineering guidelines, inform site selection, and update interim NRCS conservation standards. Additionally, the gaseous products of denitrification, nitric oxide (NO) and nitrous oxide (N_2O) and dinitrogen gas (N_2), dissolved in the DNBR, will be quantified to ensure that the bioreactors are not creating an air quality concern. This research will provide insight into the fate of nitrogen in DNBRs and allow for estimation of the quantity of reactive nitrogen removed by these systems. Additional data will also isolate the effect of biochar addition on nitrate and phosphorus removal in DNBRs.

Acknowledgements

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Additional Resources

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Glossary of Terms

Adsorption – The physical bonding of one substance to another.

Bioavailable—in a form that can be used by organisms
(i.e. plants uptake NO_3- but cannot use N_2.)

Biochar—Similar to charcoal, this form of organic carbon is produced by burning organic material, such as plant material or animal waste, at low temperature in the absence of oxygen. The resulting product is more resistant to decomposition. The method of production determines its best final use, which can be anything from a horticultural soil amendment to the charcoal for a barbeque.

Denitrification—The stepwise transformation of nitrate to nitrite, nitric oxide, nitrous oxide and ultimately dinitrogen gas, which comprises nearly 80 percent of the atmosphere.

Eutrophication—refers to natural or artificial addition of nutrients to water bodies that cause undesired effects, such as algal blooms or lowered dissolved oxygen levels.

Field Scale—Refers to use of a product or methodology in the application for which it was designed as opposed to testing in the laboratory.

Heterotrophic Microbes – Obtain energy, carbon, and reducing equivalents for reactions from organic compounds.

Leach—draining of a dissolved material as it moves with water.

Maximum Contaminant Level (MCL)—the highest concentration of a chemical that can be encountered without adverse affects to human health.

Non-Point Source Pollution—also called diffuse pollution (as opposed to point source pollution that discharges from a defined origin such as a pipe), results from land-use activity and is transported intermittently primarily by rain events.

Reactive Nitrogen—Nitrogen in a form that can participate in chemical or biological reactions, said to be bioavailable, as opposed to nonreactive (inert) nitrogen gas (N_2), which is very stable and cannot be used by organisms directly.

T.J. Kirkpatrick for POLITICO

The Agenda
WATER

The war over Chesapeake Bay

The government just paid this family to pull up productive farmland—in a huge scheme that stretches the limits of the law, but just might help save a jewel.

By ANNIE SNIDER | 05/25/16 05:17 AM EDT

LANCASTER, Pa. — Linn Moedinger's farm has been in his family for 10 generations, dating back to 1711, 150 acres of rich fields and meandering streams nestled in the heart of Pennsylvania Dutch country. As long as the family has owned it, it's been a working farm; today Moedinger leases the fields to a neighbor who grows corn, wheat and soybeans. The family relies on the crop income to keep up the historic farmhouses they call home.

Nonetheless, Moedinger recently surrendered 12 acres of property along his tiny, unnamed streams to plant wide strips of oak trees, dogwood shrubs and other native plants, paid for by the government. If all goes according to plan, that land will never produce crops again.

The trees are part of perhaps the most ambitious—and, some would say, overreaching— federal water cleanup plan underway in America. The streams on the Moedingers' property flow into Mill Creek, which drains into the Conestoga River, which flows into the Susquehanna River, which dumps roughly 25 million gallons of water each day into the Chesapeake Bay. Right now, that water includes tons of agricultural runoff that the government has been all but powerless to remove. By encouraging landowners like the Moedingers to plant trees as a kind of filter between their cropland and local waterways— and by pressuring the six states in the bay watershed to sink enormous amounts of staff time, political capital and taxpayer dollars into programs to stop farm fertilizer and animal manure from draining into the distant bay—the government hopes to solve a problem that has plagued the region for three decades: persistently high pollution that's killing one of America's most iconic bodies of water.

In the 5½ years since the Obama administration announced the Chesapeake Bay cleanup plan, it has become one of the most contentious environmental battles in the U.S. To its advocates, it's a long•overdue move by Washington to own up to its responsibility to plug the holes in U.S. water law. To opponents, it represents typical Obama excess, using the 1972 Clean Water Act as a blunt instrument to accomplish something it was never intended to do. The act gives Washington no actual power to regulate farmers; the cleanup plan gets around this by setting pollution goals for the Chesapeake Bay and then imposing limits on upstream states, effectively forcing state officials to prod their farmers into conservation programs. Without actually rewriting the law, the plan has changed land and water policy across 64,000 square miles of the mid•Atlantic. This spring, the plan narrowly survived a Supreme Court challenge, when a divided court declined to hear an appeal in a lawsuit against the government.

For the Moedingers, the decision wasn't easy, but it wasn't a fight, either. The family liked the idea of being good stewards of their land, and the state of Pennsylvania and the U.S. Department of Agriculture made it worth their while—at least for now—by not only covering the cost of the seedlings and labor, but also paying the Moedingers rent on the land taken out of production for 15 years.

"I'm not a big fan of super strict regulations, but the only way to avoid them is to be proactive, and this was something small we could do," Moedinger said on a recent visit as wind whipped through the tall streambank grasses, carrying with it the faint scent of wild meadow mint.

So far, more than 125,000 acres of forested buffers have been planted along rivers and streams in Pennsylvania's portion of the bay watershed alone. The cleanup plan, which targets all sources of pollution, has spurred states and localities to upgrade wastewater treatment plants with state•of•the•art technology, build storm•water retention ponds that slowly filter grimy water into the ground rather than allowing it to overwhelm local streams, and pay farmers to plant cover crops that bind nitrogen and phosphorus.

But as the plan takes hold, and pressure ramps up to reshape more acres of farmland to accommodate its goals, two big doubts are growing. One is among critics elsewhere in the U.S., that fear the Chesapeake Bay plan—ambitious as it is—is just the thin end of a wedge, and that the bigger target is a cleanup of the Gulf of Mexico marked by pollution that pours down the Mississippi River from farms in 31 states. They look at Obama's Chesapeake Bay effort as a framework that

could bring equally sweeping, and unwelcome, changes to the American heartland, impacting such things as farm policy, homebuilding and even how much Americans pay for day•to•day necessities like food and energy.

Another concern is that the plan, as aggressive as it is, won't be enough to save the bay. It takes decades for nutrients to work out of groundwater and for trees to mature, so it will take years to know whether the changes being made today are even working. Already, early research suggests we may have underestimated the challenge.

The Chesapeake Bay cleanup plan, along with a contentious Obama administration rule to solidify protections for small streams and wetlands, is an acknowledgment that the nation's rivers and lakes are far more difficult to protect than believed when lawmakers wrote the foremost water law. As this plan lurches forward, it's a high-stakes experiment into just how possible it is for government to protect our most crucial resource, and whether our modern way of life can ever be compatible with clean water.

THE CHESAPEAKE BAY once teemed with aquatic life: When explorer John Smith arrived in the 17th century, he found a bay enlivened by blue crabs, sturgeon, rockfish and trout, and wrote that the oysters "lay as thick as stones." The bay is the nation's largest estuary, and was once one of the most productive water bodies in the world—but it has been on life support since the 1970s. The bay receives all the fertilizer runoff, wastewater and stormwater from one of the most populated swaths of America. Its watershed stretches from Cooperstown, New York, to Norfolk, Virginia, and is home to 18 million people and growing. The result: Today the bay's iconic oyster population stands at just 2 percent of what Smith saw, and other species haven't fared much better. The blue crab population— the source of prized Maryland crabcakes—plummeted. And underwater grasses, the base of the food chain and important habitat for fish, insects, ducks and crabs, were choked out by slimy algae and sediment•laden waters.

The Clean Water Act was supposed to clean up bodies of water like the Chesapeake. When it was passed in 1972, U.S. rivers had become so fouled by sewage and industrial pollution that the Cuyahoga River famously caught fire in 1969. The law mandated massive upgrades to wastewater treatment plants and other industrial facilities, and created a whole new framework for evaluating and protecting the health of the nation's rivers, lakes and seas. In many ways, it was a huge success. Within a few short years, the raw sewage and soap bubbles that Americans had seen in their rivers and lakes disappeared. But slowly, experts realized that the nation's water bodies, especially big ones like the Chesapeake Bay, weren't all bouncing back. And the reason was something the Clean Water Act hardly addressed: What happened on the land.

Every time it rains, excess fertilizer washes off rural farm fields and suburban lawns and into local waterways. In cities and towns, stormwater sweeps over roads and parking lots, collecting grime and chemicals on its way to the sewer. As American agriculture has shifted from small family farms to large•scale, industrial production, and suburban sprawl has converted fields and forests to parking lots and big•box stores, pollution has only grown.

Today, agricultural runoff and stormwater are the largest sources of pollution in most U.S. waterways. In one sense, that's a victory for the Clean Water Act. It worked as intended, and industry and sewage are no longer the things choking rivers. But it raises a new challenge: The sources that now matter most are essentially unregulated. The entire law was written to give federal regulators the power to reduce pollution that comes out of a pipe, not pollution washing off the landscape. But as runoff surpassed industry as the main source of pollution, regulators realized that

they were still left with a massive pollution problem, but had little more to use than their power of persuasion to solve it.

And the problem goes beyond fish and wildlife. In Des Moines, Iowa, nitrogen pollution from upstream farms regularly fouls the city's source water. Last year, it forced the city's drinking water plant to spend more than $1.5 million to make water safe for consumption. Excess phosphorus from agricultural operations in Lake Erie's watershed feeds massive algae blooms on the Great Lake each summer. In 2014, one of those blooms containing a dangerous toxin reached the city of Toledo's drinking water intake pipe, forcing the city to turn off its taps for an entire weekend.

The pollution is worst at the bottom of the system, where estuaries like the Chesapeake Bay receive all the fertilizer runoff and other chemicals from an entire watershed. Agricultural runoff isn't a poison like a toxic chemical: Rather, it's a rich stew of nutrients that oversaturates the water and feeds massive algae blooms that block out sunlight and suck up oxygen when they decompose. Each summer, these blooms spawn massive dead zones that suffocate or drive away marine life. The Chesapeake Bay's dead zone regularly covers a full cubic mile during the peak of summer.

THE LONG FIGHT to do something about the Chesapeake Bay has roots that go as far back as the Clean Water Act itself. Sen. Charles "Mac" Mathias, a Republican from western Maryland, had been hearing concerns from bay residents about declining seafood harvests and industrial and municipal waste fouling a bay that he remembered from childhood as crystal clear. After a five•day, 450•mile tour of the bay in 1973 to see for himself, Mathias returned to Washington alarmed, and eventually persuaded colleagues to fund a comprehensive study of the estuary.

When the study was completed in 1983, it painted a bleak picture: decimated oyster harvests, crab yields and landings of freshwater fish—all, embarrassingly, right in Washington's backyard. The study helped fuel political will not just in Washington, but in the region's state capitals: Just months later, the governors of Maryland, Virginia and Pennsylvania signed the first agreement aimed at cleaning up the watershed. William Baker, the longtime president of the Chesapeake Bay Foundation, said the initial agreement was short on substance, but was "incredibly important symbolically," since officials in the region had long fought any suggestion that the bay had a problem.

"The phrase 'Save the Bay' was actually considered critical of this region because it implied this was not the land of pleasant living, it needed to be saved," Baker said in an interview at the foundation's bay•front headquarters in Annapolis, where ospreys glide past walls of glass windows, carrying branches for their nest and compostable toilets flush with sawdust instead of water.

The next year, President Ronald Reagan proposed a notable boost in the Environmental Protection Agency budget, in part to aid the new effort. He even mentioned the Bay in his 1984 State of the Union address. In 1987, the three states and the District of Columbia signed a new agreement setting the first numeric goals for reducing pollution. But by the time the new century rolled in, states were nowhere near the goal. They signed yet another agreement, this time including the bay's "headwater states" of Delaware, New York and West Virginia, and with even more aggressive targets set for 2010. But by 2008, it was clear those goals were going to fail as well. State officials and environmentalists knew what they needed to make the next agreement more than just another written exercise: They needed the feds.

The idea, hatched by conservation groups and state environmental officials who had seen firsthand the pitfalls of the previous, failed efforts, was to use the framework created by the Clean Water Act along with the EPA's existing powers to put real pressure on state and local governments to crack

down on runoff. Under the act, when a body of water is declared polluted, a state is required to write a “pollution diet,” defining how much of each pollutant a waterway can handle, and then chart out how much each sector would need to reduce its pollution to achieve those numbers. If a state fails to write that pollution diet, the EPA is supposed to step in to do it for them. But no one had ever tried to write a diet for a watershed the size of the Chesapeake Bay’s.

And environmentalists didn’t want just any pollution diet. They wanted one with teeth. While the Clean Water Act is clear that diets must be written, the reductions are essentially voluntary. The results have been about what one would expect: The Government Accountability Office found in a 2013 report that for waterways overburdened by pollution from farms and urban runoff, only 1 in 5 of their diets had actually been implemented after more than five years. It also included the astonishing estimate that it would take 1,000 years to clean up all of the streams, rivers and lakes ailing today with the voluntary approach.

The Chesapeake Bay Foundation and others wanted the EPA to use its powers to prod states into following through. While the agency can’t force farmers to fence their cattle out of streams or require suburban towns to build rain gardens, it can withhold grant money from communities that don’t follow through with their promises to do these things. Or, if pollution continues apace, the agency can crack down on the sources it does have control over, setting stricter permit requirements for wastewater treatment plants and industrial sources.

In January 2009, the Chesapeake Bay Foundation filed a lawsuit against the EPA, saying the agency was failing to comply with the Clean Water Act, and had violated the terms of the cleanup agreement of 2000 with the states. The goal was to force the agency to write the tough type of pollution diet that seemed necessary to clean up for the massive watershed.

The Chesapeake Bay lawsuit was one of the first major issues to land on EPA Administrator Lisa Jackson’s desk when she took office in 2009, after President Obama was sworn in. In May 2010, she signed a settlement that had the agency write the diet in collaboration with states. The goal: Get enough conservation practices in place by 2025 to reduce nitrogen flowing into the bay by 25 percent, phosphorus by 24 percent and sediment by 20 percent— amounts, it was thought, that would eventually improve water quality enough to end the bay’s dead zone.

Those total pollution reduction targets were then broken down across 92 different stream and river segments, each with its own limit. It was up to the states to write their own plans for how to hit those targets, but the cleanup plan gave the EPA a powerful oversight role. And, crucially, it laid out heavy hammers the feds could use against any state that fell short on following through.

Since then, Pennsylvania, which contributes nearly half of the nitrogen pollution that pours into the bay each year, has set ambitious goals to get farmers to write the required plans for managing nutrients and erosion on their property, and also to help them implement the plans by pushing programs like the forested buffer strips on the Moedingers' farm, which prevent excess nutrients from reaching the water. The state now puts up nearly $150 million a year for such programs.

Across the 64,000•mile watershed, researchers estimate state, local and federal authorities are pouring roughly $5 billion each year into the massive cleanup plan, covering the cost for farmers to install conservation measures, paying inspectors to visit thousands of fields, footing the bill for towns to upgrade or remove septic systems and cities to build settling ponds to store and infiltrate

stormwater. Five•and•a•half years in, the effort has already had profound changes on the way people across a broad swath of the nation's landscape use the land.

ALTHOUGH REGULATORS IN the Bay states were on board, industry groups were not.

The American Farm Bureau Federation and other agricultural and development groups filed suit almost immediately after the agency finalized the diet in late 2010. Twenty•one state attorneys general from Kansas to Florida to North Dakota—but none of the key players within the watershed—later sided with challengers, arguing the approach intruded on their rights to manage their own waters and make decisions about land use.

To farmers, this violated the deal they thought they had with the EPA. Agricultural interests enjoy major exemptions under the Clean Water Act, and have long argued that the law deliberately steered clear of telling farmers what to do. Restrictions on whether and how their land is used can hit a farmers' bottom line hard, since most compete in the global commodities marketplace that prevents them from simply raising their prices when their own costs go up. "When Congress passed the Clean Water Act in 1972, they clearly did not want to hand EPA the authority to direct land use," said Don Parrish, senior director for regulatory relations at the American Farm Bureau Federation.

The groups warned that the Chesapeake Bay would be just the beginning. They were worried that the EPA could expand the approach to other large, ailing watersheds—notably the 31•state Mississippi River watershed, which last year sent so much pollution into the Gulf of Mexico that it spawned a dead zone the size of Rhode Island and Connecticut combined. The attorneys general argued that the plan "has far•reaching implications for States across the country."

The court battle lasted nearly five years, but at each step along the way, judges upheld the bay cleanup plan. A district court judge concluded in 2013 that in the sprawling watershed, "EPA's role is critical to coordinating the Bay Jurisdictions' efforts to ensure pollution reduction." Two years later, a three-judge appellate court panel ruled for the EPA, calling challengers' arguments "long on swagger, but short on specificity."

The Farm Bureau appealed the latter decision to the Supreme Court, where its petition was considered this February in the justices' first conference after Antonin Scalia died. Looking at a potential 4-4 split on the issue, the justices declined to take up the case, allowing the district court ruling to stand but setting no precedent. That leaves the plan the law of the land in the Chesapeake Bay watershed—and it means nobody knows whether it would hold up if the EPA tried it elsewhere.

FOR ALL THE legal victories the bay cleanup effort has racked up, one huge question still hangs over the plan: Is it working? The bay has seen some recent improvements, including steep gains in the recovery of underwater grasses that provide habitat to fish, crabs and other species, and hold down sediment that can worsen water•quality problems.

But states are already falling short of their goals. Pennsylvania is particularly lagging; despite the tens of thousands of acres of forested buffers installed there and more than $4 billion poured into cleanup efforts in the past three decades, the state is sending 16 million more pounds of nitrogen downstream each year than it is supposed to under its goal for next year. Officials have already acknowledged that its 2017 target will be missed.

What happened? Democratic Gov. Tom Wolf, who took office in January 2015, has pointed the finger at his Republican predecessor for deep budget and staffing cuts to the state's Department of Environmental Protection. He has vowed to "reboot" cleanup efforts, but that would be expensive—

a Penn State University study found that Pennsylvania would have to spend $380 million a year on agricultural practices alone to make its goals—and it's not clear how Wolf and the Republican•controlled state Legislature would agree on how to find the money. The state's bay cleanup efforts suffered another blow on Friday when Wolf's Secretary of Environmental Protection resigned amid concerns he was too much of an activist to strike compromises. His move, following recent departures of two other highlevel aides, appears to leave the governor's bench of top-level environmental experts empty.

As punishment, the EPA has withheld nearly $3 million in federal grant funding, but even the agency's own officials acknowledge that also hurts the effort, since that's also funding that can help the state get back on track. And so far, the Obama administration has declined to take harsher steps like cracking down on wastewater treatment permits—in part because it's a move that could hit residents' pocketbooks and cause political headaches for the Democratic governor.

The EPA "has been doing its job all along to make sure that we're providing the appropriate backstop," Administrator Gina McCarthy said last summer, defending the agency's choice not to step in more strongly. "But honestly, you are not going to tackle the issue of restoring the Chesapeake one permit at a time, or one grant at a time. It has to be a really systemic, collaborative approach, and that is what we are supporting."

EVEN IF STATES get back on track, will the Chesapeake Bay plan really work? That's a question even its advocates have a hard time answering with certainty. Changes in runoff and nutrient levels aren't the kind of thing that can be measured day to day. The plan's achievements, like tree planting and new urban stormwater systems, require years to show improvements in local waterways. The whole plan is premised not on daily water sampling in rivers and streams, but on a complex computer model that attempts to calculate the water•quality impacts of different changes on the landscape.

Already, scientists have realized they got some of the modeling wrong. For example, researchers long thought that planting fields with minimal tilling was an all•around win, reducing soil erosion and sequestering carbon that contributes to global warming. But in recent years, scientists have come to understand that when farmers don't till the soil, extra phosphorus stays in that uppermost layer and easily washes away when a rainstorm passes through. This is an especially large problem on Maryland's Eastern Shore, right next to the Bay, where chicken producers dispose of the manure by spreading it on fields. Suddenly, state officials realized they had hundreds of farms with fields oversaturated with phosphorus—and farmers who thought they were doing something good for the environment were told they had actually been pumping gobs of harmful nutrients straight into the estuary.

Now, as the bay cleanup plan nears its midpoint next year, scientists are preparing to update the massive model underpinning the effort so it incorporates this type of new science. It will also account for changes expected to come to the bay system as the climate warms—something the current model does not account for. And as they did in Maryland, these changes could significantly move the bar for states that already struggle to meet their current goals.

People who have been grappling with water pollution issues for years, like Patrick Parenteau, a Vermont Law School professor and former state and federal regulator, say they have become realists about the chances for success. "These problems are so unbelievably serious and difficult," Parenteau said, "They are not going to be cleaned up on anybody's lifetime."

These days, he tells his students: "You can't expect success. You can only work as hard as you can, make as much progress as you can, and call it good."

Even as the Chesapeake Bay effort remains an unproven experiment, however, calls are coming from around the country for the EPA to bring the same approach to bear in other watersheds. After a toxic algae bloom on Lake Erie fouled the city of Toledo's water supply for a full weekend in the summer of 2014, the mayor pressed for the administration to step in with a similar effort in the farm runoff•plagued basin.

But the EPA has been reluctant; the agency's top water official, Joel Beauvais, said the agency is "not currently planning" any pollution diet of the size or scope of the one in the Chesapeake Bay. "The agency believes the most effective way to address nutrient pollution in other large watersheds is to continue to build on the EPA's existing cooperation with and assistance to the states, as well as collaboration with other federal agencies such as the U.S. Department of Agriculture," Beauvais said in a statement.

Agricultural groups and state officials have made it crystal clear that if the EPA ever decides to treat the vast Mississippi River watershed the way it treats the Chesapeake, it would provoke a gloves•off brawl. Even local efforts in the Midwest to reduce farm pollution have met with quick, fierce slapdowns. For example, a creative lawsuit filed last year by the Des Moines Water Works against upstream agricultural districts over its nitrate•polluted drinking water supply drew immediate blowback from Iowa Gov. Terry Branstad, who charged that the utility had "declared war on rural Iowa."

None of the remaining presidential candidates have signaled any intention of picking a more national fight. The Obama administration's controversial water efforts drew plenty of fire from Republican contenders during the lead-up to Iowa caucuses in February; on the Democratic side, candidates Hillary Clinton and Bernie Sanders have focused more on municipal water infrastructure after the lead contamination crisis in Flint, Michigan.

Whether water•quality challenges are a top priority for the next administration may not matter in the Chesapeake Bay, where the cleanup plan is settled law and the chief question is whether its measures can really turn such a massive system around. "We don't have to get the next administration to create it," said Baker, the Chesapeake Bay Foundation president. "We just have to get them not to kill it."

In Lancaster, the Moedingers are wondering if their small part of the effort will leave the next generation anything more to show for it than a patch of trees. "We're doing this on our property, but the next three aren't doing it," Moedinger said. "Will it really make a difference? Who knows." He shrugged, watching the water at his feet rush downstream.