Channelling the right tools for flood management and runoff

DairyNZ has been working with the Canterbury Waterway Rehabilitation Experiment (CAREX) group to investigate the 'two-stage channel', a promising tool to reduce landscape flooding and nutrients coming off the farm.


Catherine Febria and Jon Harding, CAREX Freshwater Ecology Research Group, School of Biological Sciences, University of Canterbury (Te Whare Wānanga o Waitaha)

KEY POINTS

- Two-stage channels deliver better management of farm waterways.
- Two-stage channels are artificially created floodplains within traditional agricultural drains. They increase flood capacity, absorb and transform nutrients, and trap fine sediment on their floodplain with minimal loss of land.
- Benefits seen overseas include reductions in turbidity of between 15-82% in flood events, increases in denitrification rates of between 35-49%, and N removal of 70% more than in unmodified channels.
- Exploring the potential for using two-stage channels requires an assessment of topography and soil types available for creating a floodplain on both sides of the channel.
- Additional environmental benefits are possible, including enhancing nutrient uptake through planting on the floodplains, trapping faecal microbes and intercepting tile drains and preferential flow paths.
- Further work is underway to determine regional rule requirements for constructing two-stage channels in New Zealand.

Introduction

Nearly two decades ago, farmers and natural resource managers in the mid-western region of the United States of America (USA) were looking for solutions to address flooding and riverbank erosion issues on-farm. Over the previous 200 years, European settlers had dramatically altered the landscapes to move water off land through extensive drainage networks and into the Mississippi River and the Gulf of Mexico. In recent times, the scale of flooding problems on farms had become so severe that solutions needed to be developed. One of these solutions was the 'two-stage channel', which reduced flooding on paddocks and improved water quality.

In 2014, Prof. Jon Harding of the University of Canterbury visited some of the two-stage channel pioneers: Prof. Andy Ward and Dr Jessica D'Ambrosio from Ohio State University, and Prof. Jennifer Tank from Notre Dame University. Together, they viewed two-stage channels of varying ages and designs, and reflected on their usefulness in addressing similar issues on New Zealand farms. The University of Canterbury and DairyNZ are now carrying out a scoping study to trial the two-stage channel as a viable farm management tool for New Zealand. The findings of this study are outlined below.

What are two-stage channels?

Two-stage channels are artificially-created floodplains established on existing farm drains. We examined the traditional two-stage channel as designed and trialled in the mid-west USA and found their issues are similar to those experienced in New Zealand. For example, agricultural drainage channels have commonly become over-engineered (straightened, narrowed and deepened) with frequent dredging and mechanical clearance to preserve and maintain drainage function. However, drain maintenance can be costly for a farmer or regulatory agency, while also contributing to negative environmental impacts, such as poor water quality. They can also have potentially counter-productive outcomes for farm management (e.g. nuisance weeds that require ongoing management).

While there has been more emphasis on altering farm practices to help manage environmental impacts, there is a growing realisation that multiple actions and tools can be employed on farm and within waterway networks to improve water quality. Two-stage channels are one such innovative tool. They can offer

Photo 1: A two-stage channel in the USA, with grass on the floodplain and a grass riparian buffer zone protecting the drain from soil runoff from the neighbouring cropping land. In New Zealand, a two-stage ditch such as this on a dairy farm would require a fence at the top of the bank on either side. (Photo: J. Harding)

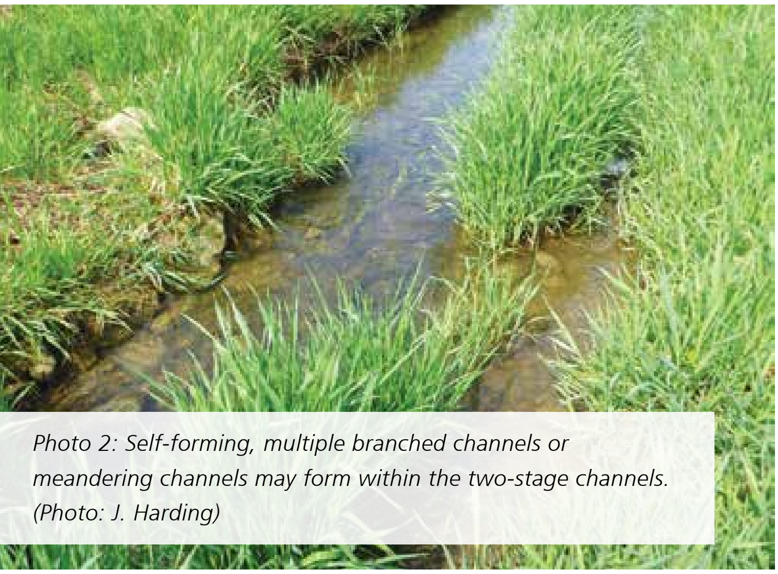

Photo 2: Self-forming, multiple branched channels or meandering channels may form within the two-stage channels. (Photo: J. Harding)

benefits for agriculture in terms of flood mitigation, and water quality and ecosystem outcomes[1].

What do two-stage channels look like?

Agricultural drains are often highly modified, straightened waterways and generally trapezoidal or U-shaped *(Figure 1a)*. In many parts of New Zealand, drains are also connected to subsurface tile drains. The two-stage channel design alters the shape of the channel to accommodate floodplains created on either side of the central channel[2, 3] *(see Figure 1b and Photos 1 and 2)*. Essentially, this creates a 'drain within a drain'.

In a two-stage channel design, the floodplain widths are about the same width as the drain on either side, banks are excavated slightly to reduce slope and bank collapse, and the exposed banks are simply grassed over. Hydrological data is used to inform the height of the bench and ensure floodwaters are effectively accommodated. As a result, the channel capacity is increased substantially.

Two-stage ditches can be created through self-forming channels. Despite the name, this is still an engineering option that involves excavating out a drain wide enough to establish initial conditions for floodplains, and then allowing other features to self-establish over subsequent flooding events[4] *(Photo 2)*. They offer similar benefits, require less excavation and are designed to allow the natural creation of sediment bars and other physical features to form over time. With either of these options, subsurface tile drains can also be accommodated in the design, with flow from tile outlets being deposited on the floodplain benches. Please be aware that excavating out a drain may require resource consent.

How well do two-stage channels work?

The two-stage channel design increases channel cross-section (therefore holding more floodwaters), lowers the power of water to damage banks, and dissipates energy across a larger cross-sectional area. This reduces the flood's power and erosion potential[5, 6, 7].

Variable water velocities are also promoted in the channels with self-forming channels facilitating the creation of natural meanders and other structural features[8]. These help reduce bank erosion and create more habitat for fish and invertebrates. Over the longer-term, two-stage channels have been demonstrated to withstand high flows for more than 10 years after construction.

What are the water quality benefits?

Studies in the USA have shown a range of environmental benefits associated with two-stage channels. They can occur either in the main channel or upon the floodplain benches. The key mechanism behind this is ensuring floodwater overtops the benches during flood events or high flows. When that occurs, the speed of the water is reduced and sediment is deposited on the benches, whereas velocities in the main channel should be

Conventional channelised channel

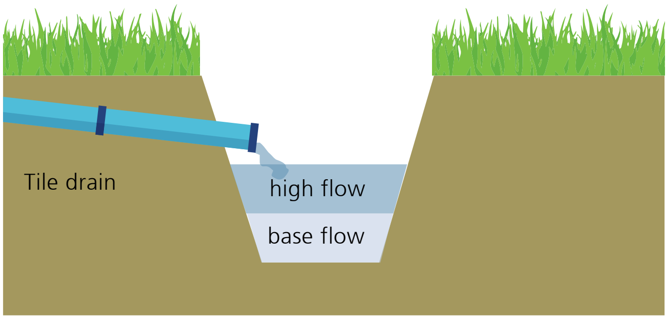

Figure 1a. Cross-section profile of a conventional channelised channel.

Two-stage ditch design

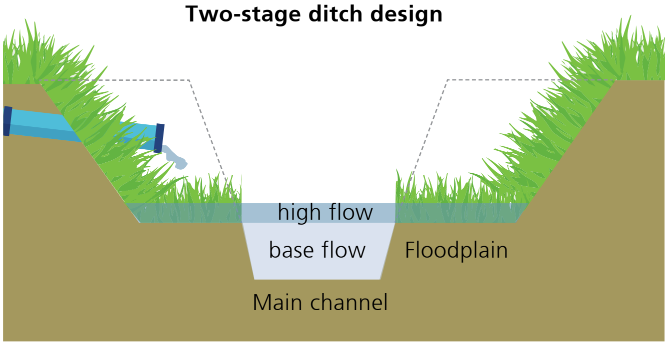

Figure 1b. Cross-section profile of a two-stage channel design[5].

higher.

As water levels drop, pools of standing water carrying sediments and other contaminants are trapped on the floodplains and nutrient removal can occur in the soils via denitrification. Published studies have shown a number of water quality improvements in two-stage channels, including for turbidity (sediment), phosphorus (P) and nitrogen (N).

Turbidity is a key measurement of fine sediments and particulates in the water column, and is an indicator of sediment loads. Studies have shown significant reductions in turbidity – a decrease of 15 to 82 percent during flood events[9]. Sites with the widest floodplains had the greatest turbidity reductions, with some suggestion that sediment retention may improve over time, and with further establishment of vegetation (e.g. plantings) on the floodplains.

There is growing evidence that two-stage channels are effective at reducing P export. Again, this is driven by floodwaters overtopping the benches and trapping P bound to fine sediment particles[7]. Like turbidity, reductions in sediment and P can be encouraged with vegetated benches[10], but further longer-term study is needed.

An additional benefit of the two-stage channel is its capacity for N removal. The primary mechanism for N removal is denitrification. Published studies indicate there is significant potential for this tool to increase N removal or uptake. Simply, denitrification occurs when floodwaters are trapped on the floodplain, and low-oxygen conditions are created in the floodplain soils, thus, supporting microbes to convert nitrate to N gas.

It follows then, that an increased floodplain area creates longer water residence time and enhanced denitrification[5]. Denitrification rates can be 35 to 49 percent higher in two-stage floodplains, compared to those without two-stage channels[11]. Another study demonstrated that most denitrification occurs when the floodplains are inundated during a storm event[9]. It found 70 percent more N was removed via denitrification compared to normal conditions.

A source of carbon is also needed to support and enhance denitrification, so vegetation and organic matter (grass, riparian plants) should be encouraged.

What about other contaminants?

Other potential benefits beyond flood mitigation, and nutrient and sediment reduction, have been hypothesised overseas[12]. These include reductions in faecal microbes, heavy metals, herbicides and pesticides. We're not aware of any published data on the ability of two-stage channels to reduce these contaminants, but we agree reductions are also likely for New Zealand waterways.

Cost effectiveness

An important factor to consider in constructing two-stage channels is their implementation cost and cost-effectiveness, relative to other mitigation tools (e.g. planted riparian buffers, constructed wetlands) used for improving water quality outcomes. While few cost-benefit analyses have been conducted, field trials have shown that once installed, several examples of two-stage channels in the mid-western USA have not required further maintenance, even 12 years after construction (A. Ward, personal communication).

Two-stages save money after 14 years

Figure 2: Cost estimation for recovering costs of excavation associated with two-stage channel implementation. *Source: Nature Conservancy, USA[1].*

A recent analysis compared two-stage channels' cost-effectiveness to other remedial actions on-farm (i.e. cover crop, wetlands) over 10- and 50-year timeframes[13]. It found the initial cost of building the two-stage channel was higher than protecting on-farm wetlands or using cover crops. However, in the long-term, the costs evened out due to minimal maintenance. This is supported by evidence from the Nature Conservancy, which suggests the payback period for excavation costs in the USA is about 14 years[1]. *(Figure 2)*.

Some farmers may initially assume the two-stage implementation requires surrendering productive land to provide space to create the floodplain benches. This is not necessarily the case. In the mid-western USA, on farms where vegetated buffers were already present along drains, little to no additional land has been required or given up. Due to the excavation required, the upfront costs may be high, but overwhelmingly the data suggests two-stage channels offer an affordable, low-to-no-maintenance, long-term solution in the USA. Tests are still to be carried out in New Zealand. However, we anticipate similar findings, particularly when existing in-stream work costs, such as erosion protection works and drain cleaning, are factored in.

Notre Dame University's Prof. Jennifer Tank, an international pioneer of two-stage channels.

Criteria for two-stage channels

Two-stage channels are seen as an exciting new opportunity in New Zealand with potential to help mitigate multiple water quality impacts faced by our farmers and communities. Internationally, two-stage channels have been shown to be highly successful. Indications are that many New Zealand farming landscapes would likely gain similar benefits. Working with DairyNZ water quality staff, our research team will install and monitor a range of two-stage channels, test their performance, identify locations that are appropriate for their installation and determine regional consenting requirements for implementation.

To provide measurable water quality outcomes, waterway reaches should generally be at least one kilometre in length. However, some studies suggest 500 metres is the minimum distance for a two-stage channel to measure a difference (Andy Ward, personal communication). Ward has indicated that only about 10 percent of the roughly 500 two-stage channels constructed to date have failed. However, almost all of these failed channels have occurred due to poor design and construction, and installing the channels in the wrong locations.

Appropriate location depends on a combination of factors, including sound understanding of the hydrological regime (e.g. frequency of flood and flood magnitude), soil type and land availability (i.e. space on either side of channel to create floodplain benches). Other considerations for New Zealand catchments include accommodating pivot irrigation (i.e. potentially requiring bridges and other infrastructure to be modified), and that spring-fed waterways with stable flows (less prone to flooding events) may not gain the same benefits where flood events fail to overtop the floodplains. Opportunities that require further testing include integrating the two-stage channel with other tools such as wetlands, riparian planting and sediment traps.

REFERENCES:

1. Nature Conservancy. 2018. The two-stage ditch is win-win for agriculture and conservation.
2. Jayakaran, A. 2007. Two-Stage Channel Geometry: Active Floodplain Requirements.
3. Powell, G. E., A. D. Ward, D. E. Mecklenburg, and A. D. Jayakaran. 2007. Two-stage channel systems: Part 1, a practical approach for sizing agricultural ditches. Journal of Soil and Water.
4. Ohio State University (OSU). Self-forming channels. URL: https://agditches.osu.edu/channel-designs/self-forming
5. Christopher S. F., J. L. Tank, U. H. Mahl, H. Yen, J. G. Arnold, M. T. Trentman, S. P. Sowa, M. E. Herbert, J. A. Ross, M. J. White, and T. V. Royer. 2017. Modelling nutrient removal using watershed-scale implementation of the two-stage ditch. Ecological Engineering 108: 358-369.
6. Fry, B. E., A. Ward, and K. W. King. 2012. The frequency of channel-forming discharges in a tributary of Upper Big Walnut Creek, Ohio. Journal of Soil and Water Conservation 67:173–182.
7. D'Ambrosio, J. L., A. D. Ward, and J. D. Witter. 2015. Evaluating Geomorphic Change in Constructed Two-Stage Ditches. JAWRA Journal of the American Water Resources Association 51:910–922.
8. D'Ambrosio, J. L., L. R. Williams, J. D. Witter, and A. Ward. 2009. Effects of geomorphology, habitat, and spatial location on fish assemblages in a watershed in Ohio, USA. Environmental Monitoring and Assessment 148:325–341.
9. Mahl, U. H., J. L. Tank, S. S. Roley, and R. T. Davis. 2015. Two-stage ditch floodplains enhance N-removal capacity and reduce turbidity and dissolved P in agricultural streams. JAWRA Journal of the American Water Resources Association 51:923–940.
10. Hodaj, A., L. C. Bowling, J. R. Frankenberger, and I. Chaubey. 2017. Impact of a two-stage ditch on channel water quality. Agricultural Water Management 192:126–137.
11. Hanrahan, B.R., J. L. Tank, M. M. Dee, M. T. Trentman, E. M. Berg, and S. K. McMillan. 2018. Restored floodplains enhance denitrification compared to naturalized floodplains in agricultural streams. Biogeochemistry:1–19.
12. Pierce, S. C., R. Kröger, and R. Pezeshki. 2012. Managing artificially drained low-gradient agricultural headwaters for enhanced ecosystem functions. Biology (Basel) 1:794–857.
13. Roley, S. S., J. L. Tank, M. L. Stephen, L. T. Johnson, J. J. Beaulieu, and J. D. Witter. 2012. Floodplain restoration enhances denitrification and reach-scale nitrogen removal in an agricultural stream. Ecological Applications 22:281–297.