Pukekauri farm – snapshots from a sustainability journey

Rick BURKE[1], Mike DODD[2*], John BURKE[3], Phil JOURNEAUX[4], Katherine TOZER[5]

[1]*181 Lund Road, RD 2, Katikati, New Zealand 3178*
[2]*AgResearch Ltd, Grasslands Research Centre, Private Bag 11008, Palmerston North, New Zealand 4442*
[3]*117 Muricata Ave, Mount Maunganui, New Zealand 3116*
[4] *Journeaux Economics, 7 Masters Road, RD 7, Hamilton, New Zealand 3287*
[5]*AgResearch Ltd, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand 3240*

*Corresponding author: mike.dodd@agresearch.co.nz

Abstract

Pukekauri Farm is a 295 ha mixed livestock hill country property in the western Bay of Plenty. Over the last 20+ years the owners have been on a development journey with a focus on the multiple dimensions of sustainability – economic, environmental, and social. This paper seeks to document that journey, with supporting resource, production, financial and environmental data to quantify progress. Some of the most useful tools have included high quality forage crops, deferred grazing, sheep genetics, accounting software and paddock-scale soil and water resource maps. Key lessons include the value of knowledge networks and modelling tools, the power of a farm plan for optimising land use and management, the importance of both profitability and grants to underwrite development investment, and the emergence of secondary benefits from decisions focused on system-wide improvement. Over 20 years, despite a reduction in grazed area of 20%, meat production has increased by 16%, EBITR/ha has increased by 6%, modelled net greenhouse gas emissions have declined by 60% and modelled N leaching has declined by 29%. Overall, the farm is easier to manage and more pleasant to dwell in.

Keywords: farm forestry, native regeneration, selective intensification, water quality

Background

Pukekauri farm was purchased by the Burke family in 1995, with the intention of developing the land into a productive and profitable unit that could enhance local biodiversity and water quality. Rick came out of a project management background in the kiwifruit industry and felt he could apply the skills learnt there, such as critical path analysis, to the challenge of sustainable farming. He admits that at the time they thought they could do this themselves, but one of their major lessons has been the value of engaging with influential and smart people, to build their knowledge of both the land and water resource and the sector dynamics. Key to this were entities such as the local B+LNZ farmer council, B+LNZ monitor farms such as the Costers, family

involvement in local pest control groups, the Project Green verification programme (Mackay et al. 2002), and tools like CashManager™ and land use capability farm maps. Rick extols the value of a farm plan to optimise land use, 'fitting the farm to the land and the land to the farm'.

The first 3-4 years were all about getting to know the farm and the importance of financial profitability for enabling development. A key weak point in this locale is the February-March warm and dry period, which puts pressure on feed supply, feed quality and animal health (i.e., heat stress, facial eczema). Rick believes this has become more acute in the last decade, and this is borne out in the climate data.

Palm kernel expeller has been used in the past to fill this gap because it is cost effective and readily available, although more recently, Rick favours home grown forage crops. Raphanobrassica and hybrid leafy turnip have been tried, and at present chicory is the crop of choice, for its ability to handle treading by the heavier animals, when planted on a suitable soil (low slope ash soils). This also provides the basis for pasture renewal, using Italian ryegrass and Kopu white clover after the crop, followed by perennial ryegrass.

The second phase in the early 2000s was very much about 'head down, bum up' work focusing on subdivision, stock water reticulation, establishing farm forestry, protecting remnant bush and riparian fencing. The work of Journeaux and van Reenen (2016) on the value proposition of stock water reticulation was particularly influential and Rick believes they have realised the authors >40% estimates of return on investment. However, they also recognise the critical support from Environment BOP in providing 50-75% subsidies for in-ground infrastructure. The old paradigm of effective pastoral area maximisation that persisted from Livestock Incentive Schemes in the 1970s had to be put to rest. Rather, "you need to have a good reason to hold land in pasture, with a particular focus on quality feed".

The last 10 years have been all about fine tuning the enterprises, underpinned by bringing in external expertise and tools. For example, the use of hydrology
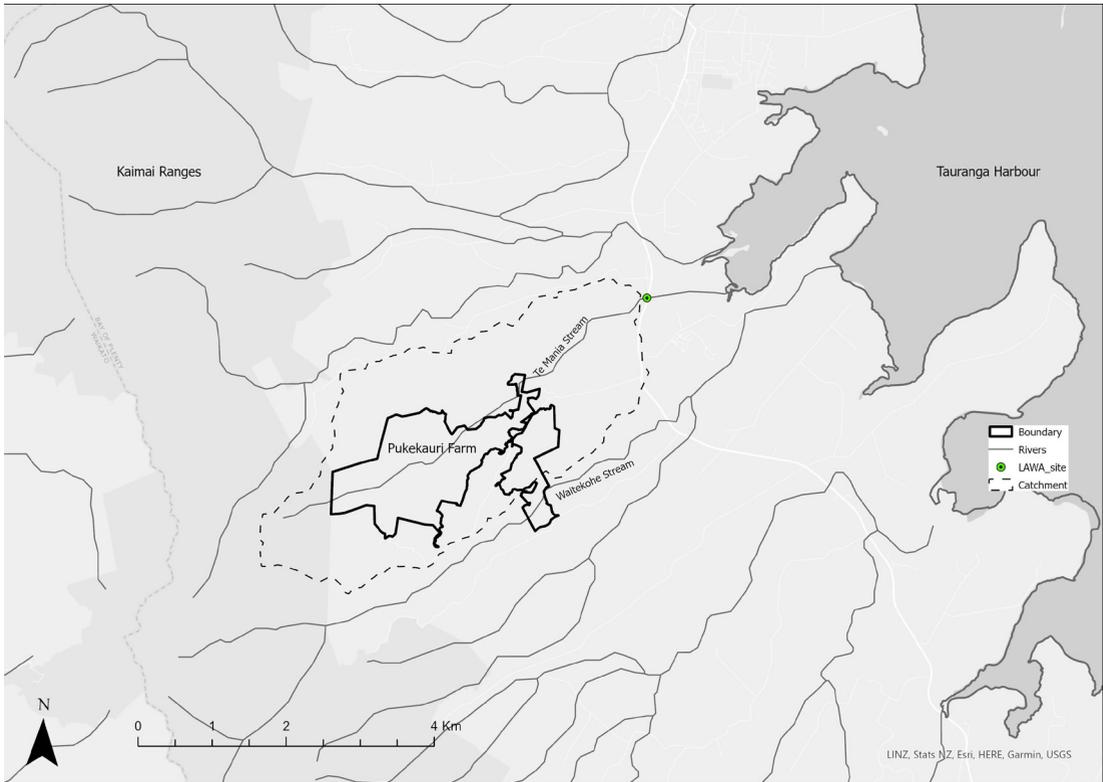
Figure 1   Location of Pukekauri farm (solid line) in the Te Mania catchment (dashed line) and Tauranga harbour catchment.

mapping to identify critical source areas and prevent sediment entering waterways, an almost literal "Fence at the top of the cliff, rather than ambulance at the bottom." Latterly, greater consideration of harvesting logistics has gone into the location of production forestry blocks. Originally, forestry was seen as a good way to control gorse and blackberry, and pines were the obvious choice, being so close to Port Tauranga. The most recent pine plantings were in 2017, but other species now used include redwood, cedar and manuka.

The following sections outline the context of the farm system, its soil, vegetation and animal resources, farm system performance from production, financial and environmental perspectives, and some commentary on the lessons learnt through the sustainable development journey.

Approach
Site characteristics
Pukekauri Farm is located 5 km southwest of Katikati in the western Bay of Plenty. It is comprised of three legal parcels of land totalling 295 ha in the hill country either side of Lund Rd (Figure 1). The topography ranges from steep to flat, but is dominantly moderately steep, as the farm is located where the Kaimai Ranges slope down toward the east and the valleys drain into the Tauranga Harbour.

Climatically, mean annual rainfall on the farm ranges from 1590-2470 mm (20-year average = 1900 mm based on the NIWA virtual climate station tool (Tait et al. 2006), and mean annual temperature ranges from 13.5-14.5°C (20-year average = 13.9°C). The seasonal pattern of rainfall shows a typically temperate Mediterranean pattern of wet winters and dry summers. While average summer rainfall at this location averages over 120 mm/month, short term summer dry periods of 6-8 weeks can be exacerbated by high summer temperatures.

On average, there are 17 days per annum with maximum temperatures >25°C, mainly in January-February (which are stressful for perennial ryegrass-based pastures). Winter temperatures are mild, with an average of 7 days of frost per annum, between June-August.

Soils on the farm are dominantly sandy loams based on volcanic tephra parent material (90%) with a small

Table 1   Classification of soil resources on Pukekauri Farm (Hanmore 2018)

Land Management Unit	Area (ha)	LUC[1] class	Soil type (dominant + other)
Easy ash pasture	32	3e1, 4e1	Katikati sandy loam (Ksl)
			+ Ksl rolling phase
Easy clay pasture	12	4e19, 4s6	Un-named loamy sands (Uls)
			and Clay loams over sandy clay
Rolling hills pasture	8	4e1, 5e1	Katikati sandy loam
			+ Ksl rolling phase
Stable hills pasture	92	4e1, 6e1	Katikati sandy loam hill soil + Ksl
Clay hills pasture	8	6e1, 6e2, 6e18	Katikati sandy loam + Uls
Steep hills pasture	29	6e2, 7e8, 5e1	Katikati sandy loam hill soil
			+ Ksl rolling phase
			+ Arahiwi steepland soil
Woodlots	24	4e1, 6e1, 6e2[2]	Katikati sandy loam hill soil
			+ Ksl rolling phase
Native vegetation	84	7e8, 6e1, 6e18, 5e1, 4w1, 6w2[2]	Katikati sandy loam
			+ Ksl hill soil
			+ Arahiwi steepland soil

[1] Land Use Capability (Lynn et al. 2009)

[2] small areas, but mainly unidentified soils

component of anthropic clay soils (10%) (Table 1). The major limitations to use are erosion on the rolling and hill soils of the Katikati sandy loam, and wetness in low lying areas of these soils. Overall, the Katikati soils tend to be moderately well to well developed, highly permeable, well drained with high water holding capacity and high phosphate retention. They are prone to structural damage under cultivation on easy terrain, and tunnel and gully erosion on the hill soils. Arahiwi soils on steeper slopes have similar characteristics. They are less well developed, with moderate phosphate retention and less prone to structural degradation (though slope effectively prohibits cultivation) but rather prone to slips and gully erosion.

There are 8755 m of perennial waterways and 4197 m of ephemeral waterways on the farm. Approximately 2 ha of low-lying areas along the main stream course have wetness limitations and have recently been converted to wetlands.

In 2018 Project Parore (https://www.uem.org. nz/projectparore), a community-led catchment management project was initiated, to raise awareness and increase landowner involvement in the restoration of land, waterways and the harbour. The project is named for a native fish, parore (*Girella tricuspidate*), that spawns in estuaries and is valued by recreational fishers. Pukekauri Farm sits with the Te Mania sub-catchment, the pilot catchment for the project that includes seven other catchments at the northern end of Tauranga harbour.

Pasture production is not routinely measured on Pukekauri farm but estimates of the seasonal pattern of pasture supply for the locality are available obtained from various sources (Fig. 2). The daily pasture growth rates peak between 50-65 kg DM/ha/d in late spring and late summer, with a mid-summer depression due to soil moisture deficit and temperature stress, and winter growth rates of 10-20 kg DM/ha/d.

Baseline situation
The 1998-99 farm system included 200 ha effective grazing land, with the balance mainly in native bush and small pine blocks. The animal enterprises included:
- Perendale/Romney cross breeding flock wintering 570 mixed age (MA) ewes with approximately 300 MA replacements (and culls) traded annually in January. Ewe weights averaged 65 kg at mating on 1 March. Lambing rates were 116% with lambing commencing 25 July. Approximately 600 additional trading lambs were purchased in November.
- Contract grazing of 200 dairy cows for six weeks in May and June (425 kg LW, aiming to add one condition score unit).
- Contract grazing of 200 dairy heifers over 12 months (arriving at 175 kg LW in May, aiming to leave at 375 kg).
- Finishing 110 bull calves purchased in November (100 kg LW) and March (180 kg LW) and sold as R1 or yearlings between July-April, depending on feed supply.
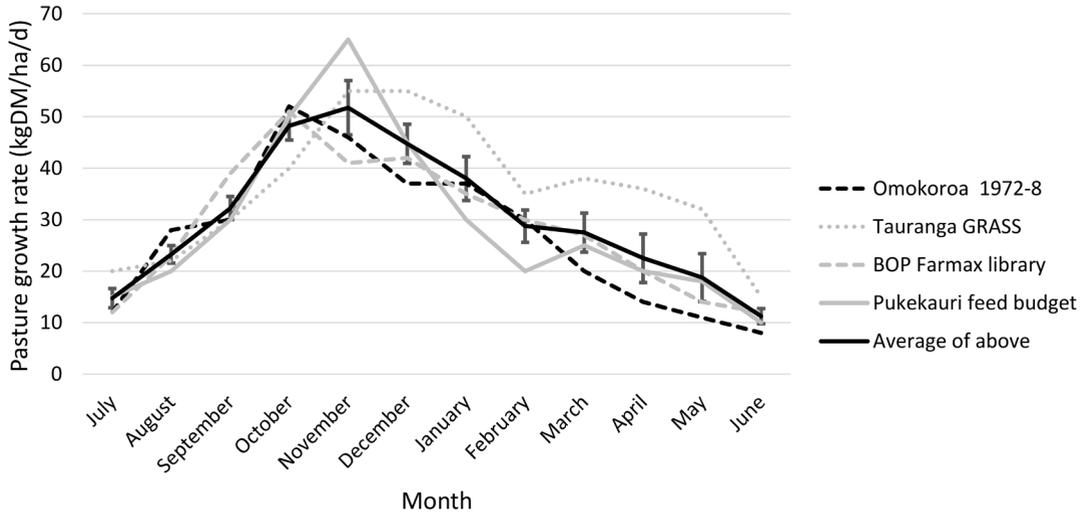
Figure 2   Estimates of mean daily pasture growth rates (kg DM/ha/d) for each month in the western Bay of Plenty Region. Sources: Omokoroa 1972-8, small plot harvests, N. Percival pers. comm.; Tauranga GRASS, Baars et al. 1991; BOP Farmax Library, Farmax Ltd; Burke budget, Pukekauri feed budget as recorded in Farmax 2018-19 production year.

System changes

Key elements of the changes in farm management on Pukekauri Farm over the 1998-2018 period included:

- An additional 10 ha was leased, i.e., by 2019 the farm system totalled 305 ha.
- Fencing of woodlots, forest fragments, regenerating native shrubland, wetlands and streams. This included critical source areas, those low-lying portions of paddocks that were persistently wet and drained into streams. The grazed effective area decreased from 200 ha in 1998 to 182.ha in 2018.
- Greater subdivision. Grazed paddock numbers increased from 62 to 91 and average paddock size decreased from 4 ha to 2 ha. In 1998 the largest paddock was 32 ha and in 2018 was 8 ha.
- Installation of stock water reticulation to all fenced paddocks.
- Production forestry with Pinus radiata (four blocks, total 18 ha) redwood (two blocks, total 1 ha) and cedar (two blocks, total 3 ha), planted between 1999 and 2018.
- Native tree planting with manuka (five blocks, total 6 ha of fenced wetland).
- Installation of sediment bunds (Fig. 3).
- Ceasing cattle grazing on specific paddocks (Fig. 3).
- Selling all cattle at a 350 kg weight threshold to avoid heavy animals on farm during winter.
- Forage cropping, currently including 6 ha of chicory on the ash soils.
- Imported supplementary feed, currently 24 t PKE purchased in March and 12 t PKE purchased in August each year.

- Use of deferred grazing on 5-15% of paddocks from late spring to late summer each year.

The animal enterprises in place during the last few seasons include:

- Perendale×Romney breeding flock 190-230 mixed age ewes with replacements bought in February as 38 kg hoggets and mated. Average ewe weights are 70 kg at mating on 1 March and average hogget weights are 40 kg at mating on 20 April. Lambing rates were 160% with lambing commencing 5 August (ewes) and 120% commencing 20 September (hoggets).
- Contract grazing of 120-140 weaner dairy heifers from November to June (arriving 90 kg LW, aiming to leave at 220 kg).
- Finishing 130-150 bull calves purchased in November (100 kg) and 20-60 R1 bulls or steers purchased in August (300 kg) and sold as yearlings or R2 between February-July depending on feed supply.

Application of technology

Modelling tools used by trusted colleagues have been critical to support both decision-making and monitoring progress. The following formal tools have been applied at Pukekauri:

- The Lincoln Farm Technical Manual (Lincoln University 2020) has been critical for informing cost-benefit assessments on various farm enterprise and stock class options.
- Land Environment Plans capture the underlying soil resource and associated characteristics of the farm system. The analysis is based on the Land

Figure 3   Farm paddock map indicating land use and management features.

Resource Inventory (Lynn et al. 2009) and enables identification of broadly consistent blocks (land management units) according to soil type, slope, limitations to use and management required to mitigate weaknesses.

- FARMAX models capture the physical livestock enterprise and financial performance aspects of the farm system. Key outputs include physical and financial performance, such as meat and wool production, enterprise, and system profitability.
- Overseer models capture some of the physical environmental performance aspects of the farm system. Key outputs include major nutrient fluxes (particularly leaching) and greenhouse gas emissions (methane and nitrous oxide).
- Carbon lookup tables (MPI 2017) provide region-specific estimates of carbon sequestration for forest plantations of Pinus radiata, exotic softwoods, exotic hardwoods, and indigenous forest. This enabled an assessment to be completed under the emissions trading scheme framework in the absence of actual tree growth measurements.

Results and Discussion

The physical performance of the farm system has improved substantially, despite the reduction in effective grazed area. Table 2 shows the key performance indicators for the livestock enterprises, in the context of the typical system for the region from the B+LNZ farm monitoring reports (B+LNZ 1999, 2019). While total opening stock units have decreased, the stocking rate has increased from 11.8 to 13.2 SU/ha, based on effective grazing area. The increase in meat production of 16% on 20% less grazed area is attributable to the improvement in sheep fecundity and changes in cattle policy.

Deferred grazing has become an important tool in supporting forage supply and quality, and ultimately animal performance. This is focused on paddocks which need pasture improvement but would be costly to re-grass. At the end of summer, Rick has a bank of feed that helps combat drought. This builds resilience into the farm system and reduces the stress of farming. The deferred pastures are rejuvenated - plant energy reserves are replenished, grasses and clovers re-seed and there is prolific pasture growth in the year after deferring (Tozer et al. 2020). Rick says that deferred pastures "might look ugly before grazing but the result is outstanding and puts dollars in your pocket". It is a cheap and easy way to re-seed pastures and if he needs the feed he can always open the gate at any time and cut the deferred period short.

The financial performance of the farm system has also improved, as indicated by the FARMAX summary data. Table 3 shows a 34% improvement in gross farm income per hectare, and while farm working expenses have also increased, the net result has been a 6% improvement in EBITR/ha.

Table 2   Physical performance attributes of Pukekauri Farm, 1998-99 vs. 2018-19 production years (July-June) compared to B+LNZ farm monitoring data (1999, 2019). na = not available.

| | Production year | | | |
| | 1998-99 | | 2018-19 | |
System	Pukekauri	B+LNZ model [1]	Pukekauri	B+LNZ model [1]
Effective area (ha)	200	423	182	434
Total opening stock units (SU)	2160	4135	1440	3846
#Breeding Ewes	570	1,828	232	1,380
#Dairy grazing heifers	200	na	134	70
#Steers+Bulls	110	155	141	203
Stock units per ha[2]	11.8	9.8	13.2	8.9
Sheep:Cattle[2]	35:65	59:41	14:86	54:46
Pasture eaten (kg DM/ha) [2]	6.35	na	6.88	na
Sheep enterprise				
Lambing (%)	116	107	159	131
Lamb sale weights (kg LW)	16.8	na	17.3	17.9
Cattle enterprise				
Bull weight gain (kg LW/hd/d)	0.76	na	0.85	na
Meat production (kg LW/ha/y) [2]	308	na	357	183

[1] North Island Class 4, B+LNZ Sheep and Beef Farm Survey

[2] Farmax files for Pukekauri

Table 3   Financial performance attributes of Pukekauri Farm ($/ha), 1998-99 vs. 2018-19 financial years (July-June) in FARMAX compared to B+LNZ monitor farm data (1999, 2019). na = not available.

| | Financial Year | | | |
| | 1998-99 | | 2018-19 | |
System	Pukekauri	B+LNZ model [1]	Pukekauri	B+LNZ model [1]
Gross Farm Income ($)	1,125	409	1,504	1,126
Net revenue	1,049	357	1,408	983
Sheep enterprise GM [2]	67	147	230	509
Cattle enterprise GM	352	113	457	343
Grazing enterprise GM	332	10	611	67
Farm working expenses ($)	543	224	744	554
Livestock purchases	473	82	876	390
Supplementary feed	15	13	38	34
Fertiliser	42	na	157	131
Animal health	16	na	48	47
EBITR ($/ha)	489	139	520	467

[1] North Island Class 4, B+LNZ Sheep and Beef Farm Survey

[2] Gross Margin

An important aspect of financial performance was the translation of the Land Use Capability (LUC) mapping into information on per hectare margins for each land management unit, and the evidence that some land management units were making a loss (particularly the steeper 6e and 7e, Table 1). This was attributed to high fixed costs (fertiliser, weed control, R and M) relative to animal production from *in situ* forage supply, also considering stock losses and the amount of 'management time' spent in these areas (with the associated hassle, i.e., mental health drain). Rick's recreational pursuits include surfing and fishing, hence there was a natural connection between the amount of time left over for these activities and the environmental state of the harbour. Changes such as steepland afforestation, riparian fencing and sediment bunds

Table 4 Modelled environmental performance attributes of Pukekauri Farm.

Environmental metrics	1998-99	2014-15	2020-21
Farm pasture area (ha)	200	182	162
Farm nutrient balances			
Nitrogen losses (kg N/ha/y)[1]	21	19	15
Phosphorus losses (kg P/ha/y)[1]	0.8	0.9	0.8
Greenhouse gas balance			
Methane emissions (t CO_2e/ha/y)[1]	2.90	2.37	2.24
Nitrous oxide emissions (t CO_2e/ha/y)[1]	0.81	0.67	0.64
Total biological emissions (t CO_2e/ha/y)[1]	1080	883	842
Conifer sequestration (t CO_2e/ha/y)[2]	nil	21.58	21.58
Native tree sequestration (t CO_2e/ha/y)[2]	nil	6.48	6.48
Net farm emissions (t CO_2e/y)[3]	873	553	349

[1] OverseerFM file for Pukekauri, based on whole property area.

[2] Assuming averaging applied across all blocks, based on MPI (2017).

[3] Including forestry carbon sequestration.

provided a solution that met both concerns.

Key environmental performance metrics are shown in Table 4. Reductions in both nitrogen losses and greenhouse gas (GHG) emissions on a per hectare basis were observed, bearing in mind these are calculated for the whole farm area, so some of the effect is attributable to the reduction in pastoral area alone. Set against the increases in animal production noted in Table 2, this translates into a reduction in emissions intensity, consistent with industry-wide analyses (Mackay et al. 2012). The factors identified in the that study were also at play here i.e., increased fecundity and a greater proportion of feed utilised by young growing livestock.

Data from Environment BOP indicated that the Te Mania stream was a large contributor to sediment entering Tauranga Harbour. This was directly attributable to heavy cattle soil damage on class 6e and 7e steeplands, where they had direct access to streams. Hence a major focus of mitigation was fencing these critical source areas, with significant support from Environment BOP funding. A secondary benefit of cattle exclusion and reticulation was the elimination of liver fluke problems.

Greenhouse gas emissions per hectare and in total across the whole farm have been decreasing (Table 4). The per hectare GHG emission from the pastoral area increased in 2020/21 due to a higher stocking rate, but the whole farm figure decreased due to a lesser area in pasture. By comparison, the average gross GHG emission from the North Island Class 4 farm is 3.9 tonnes CO_2e/ha, or a gross total of 1,693 tonnes CO_2e, with a range of gross emissions across this farm class from 2.1-5.9 tonnes CO_2e/ha (Vibart et al. 2020). The carbon sequestration from the trees assumes that the conifers are eligible for the new averaging scheme

(which came into force in January 2023), giving an area-weighted sequestration of 18 tonnes CO_2e/ha/y (MPI 2017). The main factors for reducing overall emissions involve reducing total dry matter intake through having less capital stock on a smaller grazing land area (lower biogenic methane) and reducing N fertiliser through tactical use on smaller and more responsive areas (less soil nitrous oxide emissions). To offset the effects of this on overall animal production meant increasing feed use efficiency through better pasture utilisation on favourable land classes, i.e., 3, 4 and 5, directing more pasture grown into productive young stock, and finishing stock faster, all of which result in lower emissions intensity (Leslie et al. 2008, Dodd et al. 2020).

Given the ongoing focus on improving water quality, data from the LAWA website provide information on the outcome at the lower Te Mania catchment. The stream has been monitored monthly at SH2 (Fig. 1) by Environment BOP staff from 1990 until the latest published data in 2017 (Table 5). The limited data from pre-1992 indicated the highest measured levels of suspended solids, phosphorus, and water temperature. While the results show no clear pattern for the period 1990-2002, there does appear to be some patterns of improvement from 2003 onward, in terms of reductions in suspended sediment and dissolved reactive phosphate, and an improvement in visual clarity.

For water temperature and nitrogen, while results from the 2013-17 period are lower than the 2008-12 period, there is no obvious trend for improvement at this point. These numbers highlight the variability that can be seen in environmental data, resulting from factors such as climate and weather variability, and other activities within any given catchment. The data also

Table 5   Mean water quality characteristics of the Te Mania stream at State Highway 2 (1990-2017). Data are 5-year averages from monthly sampling, available from the LAWA portal at https://envdata.boprc.govt.nz/Data/Location/Summary/Location/BQ711622/Interval/Latest

Water quality metric[1]	<1992	1993-97	1998-02	2003-07	2008-12	2013-17
Total suspended solids (g/m^3)	38.9	7.0	9.4	17.4	13.8	7.9
Visual clarity (black disc, m)	-	1.3	1.4	1.2	2.0	2.2
Water temperature (°C)	15.2	13.5	15.1	15.0	15.2	14.7
E. coli (*cfu*/100ml)	-	266	435	1063	414	793
Nitrate+nitrite N (mg/m^3)	-	318	305	305	315	278
Total N (mg/m^3)	-	-	-	-	435	380
Dissolved reactive P (mg/m^3)	11.4	11.6	9.1	10.5	5.4	6.1
Total P (mg/m^3)	57.1	21.5	14.3	22.3	23.4	24.8

[1] average of monthly sampling for each 5-year period between 1990-2017

emphasise the reality of lag effects between activities and outcomes even in small catchments. Stream health is also assessed with an overall rating, incorporating several individual measures, and this went from 2/10 in 1998 to 9/10 in 2018.

Some of the most satisfying benefits arising out of the development journey weren't necessarily part of the plan, such as: the mental well-being that comes from working in a diverse environment; the return of native birds such as fantail, tui, kereru and kōtare – even kiwi have been heard although not yet sighted; the knowledge that the system is mitigating GHG emissions, as a direct result of decisions taken to improve farm system performance, biodiversity and water quality even before climate mitigation was an imperative.

Conclusions

The overall message is the importance of matching both land use <u>and</u> land management (within use i.e., which stock types, which trees, which crops) to land capability. To do this well, you need to have mapped LUC at the right scale. This enables the development of a robust farm environment plan. Few farm managers have the skills to do this, and then apply the relevant modelling tools to assist decision making, which emphasises the value of 'hired guns' where farmers may have areas of limited expertise, such as GHG and biodiversity. Developments in genetics and management tools (e.g., deferred grazing, cover crops) have been critical for improving profitability in the face of rising costs and obligations. Key factors for improving water quality were to identify critical source areas, reduce sediment generation by cattle on steep lands, capture sediment in lower slope areas with small detainment bunds, and reduce N losses with small wetlands. Financially, it was important to maximise leverage of regional grant monies for these activities (fencing, planting, reticulation).

REFERENCES

Baars JA, Goold GJ, Hawke MF, Kilgariff P, Rollo MD. 1991. Seasonal patterns of pasture production in the Bay of Plenty and Waikato. *Proceedings of the New Zealand Grassland Association 53*: 67-72. https://doi.org/10.33584/jnzg.1991.53.2007

B+LNZ (1999, 2019) Sheep and Beef Farm Survey, North Island Class 4. https://beeflambnz.com/industry-data/farm-data-and-industry-production/sheep-beef-farm-survey

Dodd MB, Rennie G, Kirschbaum MUF, Giltrap D, Smiley D. 2020. Improving the economic and environmental performance of a New Zealand hill country farm catchment: 4. Greenhouse gas and carbon stock implications of land management change. *New Zealand Journal of Agricultural Research 64(4)*: 540-564. https://www.tandfonline.com/doi/abs/10.1080/00288233.2020.1775656

Hanmore I. 2018. Land and Environment Plan prepared for John Burke, Pukekauri Farm. AgFirst Consultants, Whangarei. 31 pp.

Journeaux P, van Reenen E. 2016. Economic evaluation of stock water reticulation on hill country. Report for MPI and B+LNZ, 56 pp. https://www.mpi.govt.nz/dmsdocument/15478-Economic-Evaluation-of-Stock-Water-Reticulation-on-Hill-Country-

Leslie M, Aspin M, Clark H. 2008. Greenhouse gas emissions from New Zealand agriculture: issues, perspectives, and industry response. *Australian*

Journal of Experimental Agriculture 48: 1-5. https://doi.org/10.1071/EA07306

Lincoln University (2022) Farm Technical Manual Vol 24. Faculty of Agribusiness and Commerce, Lincoln University. https://aginfo.lincoln.ac.nz/manual/farm-technical-manual-vol-24-annual-subscription/.

Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Douglas GB, Mackay AD, Newsome PJF. 2009. *Land Use Capability Survey handbook – a New Zealand handbook for classification of land.* 3rd Ed. AgResearch, Hamilton; Landcare Research, Lincoln, GNS Science, Lower Hutt 163 pp.

Mackay AD, Rhodes AP, Power I, Wedderburn ME. 2012. Has the eco-efficiency of sheep and beef farms changed in the last 20 years? *Proceedings of the New Zealand Grassland Association 74*: 11-16. https://doi.org/10.33584/jnzg.2012.74.2878

Mackay AD, Thomson B, Grant L, Burgess T, Stokes S, Gray R, Webby R, Donald L, van de Weteringh R, Cook T, Pearce R. 2002. Land and environmental management. An opportunity not a cost. *Proc. Southern North Island Sheep and Beef Cattle Farmers Conference 11*: 31-42.

MPI. 2017. Carbon look-up tables for forestry in the emissions trading scheme. Ministry for Primary Industries, Wellington. 42 pp.

https://www.mpi.govt.nz/forestry/forestry-in-the-emissions-trading-scheme/emissions-returnsand-carbon-units-nzus-for-forestry/calculatingthe-amount-of-carbon-in-your-forest-landcarbon-tables-for-calculating-carbon

Vibart R, Rennie G, Hutchinson K, Burtt A, Chrystal J, Dynes R. 2020. Greenhouse gas emissions from New Zealand sheep and beef farms. *Journal of New Zealand Grasslands 83*: 225-232. https://doi.org/10.33584/jnzg.2021.83.3501

Tait A, Henderson R, Turner R, Zheng. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology 26*: 2097–2115. https://doi.org/10.1002/joc.1350

Tozer KN, Müller K, Tarbotton I. 2020. *Deferred Grazing Handbook.* Hamilton, New Zealand: AgResearch Ltd, 32 pp. https://www.agresearch.co.nz/our-research/deferred-grazing-handbook/