Farm level Case studies

Five case studies were undertaken for detailed analysis over the full crop cycle to enable better understanding of finer-scale farm-level variability of trade-offs between water saving and increased energy (and GHG) energy consumption. In the integrated analysis, the information on crop yield, energy use, prices received, input use, water and labour used and capital and operating costs and so on for both the systems is based on the farmer's records and accounts. To fill gaps in the data required for the analysis, information was collected through personal discussions with the local irrigation and industry people and the technical staff involved in the project.

Enterprises assessed included three cotton farms on the Darling Downs, a vegetable (lettuce) farm in the Lockyer Valley and a pasture-cropping (lucerne, oats) and vegetable (onion) farm on the southern Downs (all in southern Queensland). Irrigation technology transitions investigated were from flood (furrow) to overhead sprinkler (lateral-move and/or centre-pivot), from flood (furrow) to drip (trickle), from overhead sprinkler (hand-shift) to drip (trickle), and from overhead sprinkler (roll-line) to improved overhead sprinkler (centre-pivot) systems.

Case study 1: Cotton Farm, Darling Down, southern Queensland

Farm description and parameter estimation

This farm is a mixed irrigation/dryland farming enterprise on the Darling Downs, southern Queensland, producing cotton and grain (wheat, corn). Cropping soil types are light dispersible clays (light box country) to heavy alluvial black cracking clays with high soil moisture-holding capacity. Irrigation water sources on this farm are from overland flows (authorized water-harvesting) diverted from an unregulated watercourse. Harvested water is stored in on-farm storages or 'ring tanks' (authorised storage capacity) and distributed to irrigation paddocks by open channels. In a normal irrigation season this farm relies on 2 to 4 ML/ha of water for irrigation, applied by lateral-move sprinkler irrigators and surface (furrow) irrigation, respectively.

Property development: The property was set up for surface irrigation when purchased. This area was expanded in 1996, and 2 lateral-move sprinkler systems were purchased in 2006. Currently, 453 ha are irrigated by furrow and 154 ha by lateral-move sprinkler irrigation. There are plans to convert another 180 ha to lateral-move in the future. Price is seen as a major barrier to the adoption of new irrigation technologies, but this is managed on a risk-management basis, with current investments paid off before additional systems are purchased. At the time of purchase, establishment costs for the lateral-move sprinkler system were approximately 155% above those for surface irrigation ($3,250/ha and $1,270/ha, respectively). The additional pumping cost is about $45/ML. Additional barriers to adoption relate to the pre-existing shape and/or orientation of paddocks.

Cropping system: Farming is on a 4-5 year crop rotation with 2-3 crops of cotton (irrigated, dryland), followed by wheat (double-cropped, dryland), then corn (irrigated) if sufficient water is available (if not, the paddock is fallowed), then back into cotton. At any one time, 2/3 of the irrigation area is planted to cotton, and 1/3 to grain (corn, wheat) or fallow. This farming system is essentially opportunistic, with the area of irrigated cropping determined by water availability. Water savings achieved through the use of the lateral-move sprinkler systems (estimated at 2 ML/ha) allow an increased area of irrigated crop to be grown in any one season, and/or carry-over which provides insurance in terms of available water for planting in the next season. This is critical as rainfall patterns in the region are highly variable and storages on this property are filled on average once every two years.

Technology adoption: Principle drivers for adoption of new irrigation technology were stated as increased productivity and terms of trade, rather than water savings. To quote: "*Adoption was about everything – greater flexibility, increased productivity, increased cropping intensity, reduced labour, fewer workings of paddocks and water saving,"*. Farming operations under sprinkler irrigation do not require furrow preparation, although furrows have been retained on this property to enable storm water control. Greater water savings are possible on the lighter country (15% savings for the same level of productivity); on heavier soils, there is a similar level of water use (i.e., little water saved), but better productivity is achieved.

The lateral-move sprinkler systems allow better control of moisture levels in the soil profile. Soil moisture levels and crop requirements are determined through monitoring, and a deficit irrigation protocol is followed. This is less easily controlled using flood irrigation, where crop stress needs to be anticipated due to the length of time taken to complete a water application. In addition, flooding provides a full profile of soil moisture, which is not always useful, and over-watering issues can arise when rain follows water application.

Drip irrigation has been considered on this farm. However, there are a number of issues which make it a less attractive option. These include damage from pests (mice and crickets) and soil movement on self-mulching clay soils, and the relatively short life-span (15 years) of drip systems. Overhead irrigation has a much better life-span and "can be taken away" (i.e., value can be recouped). Drip irrigation is possibly a better option on sandy soil types.

Other technologies adopted include GPS technology, enabling straighter cultivation and less wear and tear on drivers, and licensed Bollgard and Round-up Ready GM crops, with associated benefits is terms of reduced paddock workings and herbicide use.

Crop production: Production benefits are seen in terms of increased yields and improved quality under the lateral-move system. In 2009, cotton grown under a lateral-move system yielded 2.6 tonne/ha (0.65 tonne/ML) while a crop grown on furrow irrigation (but also lighter soils) yielded 2.2 tonne/ha (0.37 tonne/ML). While some of this difference could be due to different soil types in the different paddocks, this landholder also reported greater corn production of 11.9 tonne/ha (4.0 tonne/ML) under lateral-move irrigation compared to 10.4 tonne/ha (2.9 tonne/ML) under flood irrigation on the same soil type. In these instances, yield improvement per hectare for cotton was 18% but 77% per ML of water; for corn, this was 14% and 38%, respectively.

In addition, better cotton fibre quality (longer staple) was maintained where irrigation (and available soil moisture) was able to be extended over longer periods (i.e., under the lateral-move system), although this has not been measured. However, it was felt that increased productivity could not be attributed solely to lateral-moves; in reality, it is due to a combination of all conditions. Cotton staple is most likely to be affected when water is short, often resulting in discounted price for cotton grown under dryland conditions.

Labour saving: While new irrigation technologies have meant reduced labour requirements, they also require more management and greater skill. A lot of this time involves checking and maintenance (estimated at 20 hours/crop), and savings are not really evident at this scale, though may be at the scale of Cubbie station, for example. Labour is now usually sub-contracted (mechanics, electricians, consultants etc). As a result, although lateral-moves have probably resulted in 20% labour saving (in hours) over flood, overall costs are similar and labour saving benefits are reduced because of the increased cost of skilled labour,

Crop inputs: Nitrogen application is expected to increase in the longer term because of the increased frequency of cropping (fertilisers are applied on the basis of soil tests): the more crop grown the more fertiliser is needed. Some fertiliser application has occurred through the lateral-move sprinkler system, which is expected to deliver greater efficiency of N use, but there are no specific figures to back this up. There has, so far, been no evidence of increased requirement or nutrient tie-ups, and there is no water logging in this system so denitrification would be minimised.

In recent years there has been more long-fallow cropping, hence natural N build up, and less fertilizer needed (based on soil tests). The standard level of N application is 200 kg N/ha; on fallow, this can be reduced to 100 kg N/ha. Similarly, if there is a crop failure N is generally available for the next crop. There has been no evidence of denitrification except in areas where flood irrigation and rainfall events cause ponding. The farm has been laser-levelled, so there are limited problem, but this may not be as big a problem on the soil types here in any case.

The application of crop sprays has been minimised under the lateral-move systems by planting GM (Bollguard, RoundUp Ready Flex) cotton, although conventional cotton is still grown on the flood paddocks as spraying here is easier (ease of turning boom sprays etc). After Christmas, most spraying is by aeroplane in both systems.

Herbicide application is on a paddock by paddock basis. More weeds are germinating with additional watering, which can be an issue for some crops (e.g., corn) grown under the lateral-move system. However, this is not resulting in greater use of herbicides; instead, it is being managed through longer term rotations, while herbicide can be applied when GM cotton is grown.

Soil health: Soil carbon content is likely to increase under the lateral-move system, due to a combination of minimum till (fewer cultivations with the lateral-move system) and increased frequency of cropping (stubble from 6 crops in 3.5yrs), even though not all of these are grown on full water (i.e., some are rain grown).

Climate change: Water savings are dependent on soil conditions and climate variables during the growing season, and future climate change is likely to increase the need for efficient water use. Climate change was seen as beneficial for irrigated cotton enterprises already set up to cope with ephemeral rains, with dams currently filling, on average, every two years. High intensity rain is better for overland flow harvesting; longer dry periods between rain events are also beneficial for cotton when deficit watering is possible.

Water trading: This landholder stated that he would not be interested in “giving saved water back” through government water buy-back initiatives. While water savings are evident in the examples given above, there is no conclusive evidence that this is the case in every year or that a predictable quantity of water can be saved. Further variables need to be taken into account, including evaporative losses from storage dams (which can be as high as 20%) and seepage losses (estimated at 3 mm/day). In any case, water in this location is not really tradeable; storage volumes are linked to land title and would need to be separated to enable trade, and transfer of water volumes in storages situated away from the river is currently physically not possible.

Case Study 2: Cotton Farm, Darling Downs, southern Queensland

Farm description and parameter estimation

This farm is a 1700 ha mixed irrigated cropping and riparian grazing enterprise on the Darling Downs, southern Queensland. The cropping component (1335 ha) produces cotton, lucerne and/or grains (wheat and sorghum). Cropping soil types are black cracking clays (Vertosols). Irrigation water sources on this farm are licensed streamflow harvesting from unregulated watercourses (nominal volumes, seasonally-adjusted allocations), diversion of overland flows (licensed volumetric limits) and groundwater (nominal volumetric entitlements, allocated volumes). Harvested water (all sources) is stored in on-farm storages or 'ring tanks' (authorised storage capacity) and distributed to irrigation paddocks by open channels. In a normal irrigation season this farm relies on 4 to 5 ML/ha of water for irrigation, applied by lateral-move and centre-pivot (sprinkler) irrigators and flood (furrow) irrigation, respectively.

Property development: The property was originally set up for flood irrigation. Since 2002, parts of the flood irrigated area have been converted to lateral-move (3 systems; 503 ha in total) and centre-pivot sprinkler (1 system; 60 ha in total) irrigation systems. Selection of paddocks for conversion to sprinkler systems was based on soil type (heavier soils) and paddock shape, particularly for the lateral-move systems which require large rectangular paddocks. Remaining flood fields (772 ha) are generally more sloping, with 'better' (slightly lighter) soils. There are no immediate plans to convert further area to sprinkler systems in the future. Major barriers to the adoption of new irrigation technologies include price, the pre-existing sizes and shapes of paddocks, and lack of consistency with regard to water availability and hence the need to prioritise investments.

Total water storage capacity on this property is 4.6 GL. However, on average, storages are filled only once every 2-3 years. Rainfall and streamflow patterns in this area are highly variable, and water scarcity is a significant concern. Access to nominal in-stream harvesting volumes is subject to restrictions based on flow rate. In addition, local groundwater tables are declining and there are increasing restrictions (allocation is currently 60% of nominal entitlements) on extraction. Overland flow harvesting is a cheaper option, but only possible with storm rainfall runoff and subject to pumping restrictions. On average, stored water comprises 20% groundwater and 40% each from streamflow and overland flow diversions. Access to a range of water sources enables a degree of risk-management, while mixing of water sources is also beneficial to avoid salinity issues associated with continuous use of poorer quality groundwater.

Water use efficiency associated with the sprinkler irrigation systems is assumed to be around 90%, however this is probably reduced due to evaporative and transmission losses (~ 10%) to around 80% on a whole farm basis. Up to 1.5 m/year is lost to evaporation and/or seepage from ring tanks.

Cropping system: Farming is on an opportunistic basis, with no set rotation. The area cropped and crop planted are determined by water availability and market prices. Water savings achieved through the use of the sprinkler systems (estimated at 1 ML/ha) allow an increased area of flood-irrigated crop to be grown in any one season, and enable carry-over which provides insurance in terms of available water for planting in the next season.

Technology adoption: Principle drivers for adoption of new irrigation technology were stated as more efficient management of available water and improved economics ("*more income with the same amount of water*"). Water goes 30% further, enabling an increase in the cropping area each season as well as improved productivity on sprinkler-irrigated crops. Other technologies adopted include licenced Bollgard and Round-up Ready GM crops, with associated benefits in terms of reduced paddock workings and pesticide use. Soil capacitance probes (and consultants) are used to monitor soil moisture for irrigation scheduling.

Crop production: Production benefits are seen in terms of increased yields and improved quality (price differential) under the lateral-move system. In an average year, cotton grown under sprinkler systems yields 10 round bales (227 kg each) per ha compared to 8.5 to 9 bales/ha for flood irrigation, and is less likely to suffer quality discounts. The equivalent per hectare and per ML productivity is 2.3 tonne/ha and 0.58 tonne/ML for sprinkler irrigated cotton and 1.9 – 2.0 tonne/ha and 0.39 – 0.41 tonne/ML for flood irrigated cotton. Yield improvement due to the adoption of sprinkler irrigation systems is estimated to be 15 to 21% per hectare and 42 to 49% per ML of water in paddocks irrigated, with additional economic benefits due to improved quality.

On average, the sprinkler systems can produce the same yield as flood systems on 30% less water, or, at less than full water, there will be a 30% higher yield with overhead compared to flood for the same amount of water applied. However, on full water, flood irrigation on this property will out-yield the sprinkler systems and quality is maintained. In poorer years, the overhead systems allow water to be spread out to maintain the crop, while flood systems will suffer stress between watering. As a result, the sprinkler systems will produce double the yield of flood systems, which will suffer a 50% yield reduction as well as quality discounts.

Labour saving: The new irrigation technologies have reduced labour requirements on this property. The machines are able to be managed by the property owner, while the flood irrigation paddocks require 2 extra people.

Crop inputs: Nitrogen inputs are reduced under the sprinkler systems. Each system (flood, sprinkler) receives 5 tonnes/ha/year of animal manure from local feedlots, while urea and/or gas are applied at an average rate of 400 kg/ha in the flood system and 300 kg/ha in the sprinkler-irrigated systems. The sprinkler systems offer significant benefits in terms of fertiliser application as they enable smaller, more frequent applications in line with crop requirements over the cropping season.

There is no difference in the application of crop sprays (pesticides, defoliants) in the flood and sprinkler-irrigated systems on this property, although overall requirements for herbicides and insecticides have been minimised by planting GM (Bollgard, RoundUp Ready) cotton.

Climate change: Increasing water scarcity will necessitate more efficient management of available water. Currently, climate forecasts are noted, and planting areas are adjusted if an El Niño year is predicted; irrigation scheduling is influenced by daily, weekly and 30-day forecasts, and less water may be applied if rain is expected (i.e., higher probability of rain).

Water trading: Water trading has not been considered, however price would be a factor influencing any decision to trade. If a higher return could be made by trading water, it could be better to sell than to grow a crop. However, only temporary trades would be considered.

Case Study 3: Cotton Farm, Darling Downs, southern Queensland

Farm description and parameter estimation

This farm is a 1011 ha mixed irrigated and dryland grain and cotton cropping and piggery enterprise on the Darling Downs, southern Queensland. Of the total area, 227 ha is irrigable and the remainder is dryland. Cropping soil types are Waco self-mulching black cracking clays (Vertosols). Irrigation water sources on this farm are from diversion of overland flows (licensed volumetric limits) and groundwater extraction (nominal volumetric entitlements, allocated volumes). Harvested water from both sources is stored in on-farm storages (authorised storage capacity). Mixing of bore water and harvested overland flows is critical to maintaining water quality (bore water is from the edge of the Condamine Alluvium and is of relatively poor quality) and for ease of distribution. In a normal irrigation season this farm relies on 5 to 6 ML/ha of water for irrigation, applied by drip (trickle) and flood (furrow) irrigation, respectively. Distribution to flood irrigation paddocks is by open channels and to drip irrigation paddocks by pipe.

Property development: The property was originally set up for flood irrigation. In 2005, 37 ha were converted to a drip irrigation system in order to improve water use efficiency and to address water quality concerns ('*less water means less salt, and the drip system keeps the water away from plants*'). There are no immediate plans to convert further area.

The total water storage capacity on this property is 0.58 GL, with a 60% reliability (RUSTIC) rating (although under current conditions, the probability of filling is around 30 – 40%). Rainfall patterns in this area are highly variable, and water scarcity is a significant concern. The local groundwater table fell significantly (about 20 m to 80 m) in the decade following the commencement of irrigation in the local area in the early 1990s, but is currently stable; groundwater allocations are currently 70% of nominal entitlements. The increased depth to groundwater has increased the cost of pumping; in addition, the recharge rate is reduced, so pumping is slower. This has meant that the bores have to be started earlier in the season to enable stockpiling into the dam for the coming irrigation season.

While drip irrigation was adopted to increase the efficiency of water use on the farm, the actual WUE of this system is unknown. Drip irrigation reduces water use at planting (pre-watering and germination) by about 1 ML/ha, but once the crop is established, water use is about the same as flood. Additional water savings are achieved as there are no head ditches (or transmission losses) and there is less evaporation in the paddock. Trickle tape is buried at a depth of 100 mm, and water is applied close to the root zone of plants.

Cropping system: Farming is on an opportunistic basis, with no set rotation. The area cropped and crop planted are determined by water availability ('*we farm moisture*') and market prices. Water savings achieved through the use of the drip system (estimated at 1 ML/ha) allow an increased crop area to be grown in any one season, and/or reduced risk for the current crop ('*we are supplementary irrigators*').

Cotton is planted on a single skip 60" configuration (i.e., 1.5 m rows) for all farming systems (flood, drip and dryland) on this property. This enables the use of just one set of gear (cultivators etc), and the drip system is able to wet across this configuration. This effectively means that 66% of the area is actually planted, which is feasible as the Bollgard licence is based on green area planted. It also means that input costs are reduced by 33% compared with planting on a 40" configuration.

Technology adoption: Principle drivers for adoption of drip irrigation technology were stated as increased crop productivity, reduced input costs and economic profit. It was felt that, with the trickle tape expected to last 10 years, the economic differential would be realised.

Major barriers to further adoption of new irrigation technologies include outlay costs ($1,950/ha), water quality (limiting the conversion of dryland area to drip), and the efficiency of existing flood irrigation. Concerns were expressed with regard to waste issues at the end of the 10 years, and the need to improve the labour efficiency of installation and removal. Problems encountered have been predominantly leaks due to rodents and mechanical damage, but these are readily spotted (wet spots in furrows and runs, and sprays).

Other technologies adopted include licensed Bollgard and Round-up Ready GM crops, with associated benefits in terms of reduced paddock workings and pesticide use. Neutron probes (and consultants) are used to monitor soil moisture for irrigation scheduling.

Crop production: Production benefits are seen in terms of increased yields and improved quality (price differential) under the trickle irrigation system. In an average year, cotton grown on the drip system yields 0.45 bales/acre better (4.2 bales/acre) than flood irrigation (usually 3.75 bales/acre), and a 10% improvement in quality (longer staple). The equivalent per hectare and per ML productivity is 2356 kg (2.4 tonnes)/ha and 491 kg (0.5 tonnes)/ML for trickle irrigated cotton and 2103 kg (2.1 tonnes)/ha and 363 kg (0.4 tonnes)/ML for flood irrigated cotton. On these values, yield improvement due to the adoption of the trickle irrigation system is 12.0% per hectare and 35.3% per ML of water compared with flood irrigated yields.

Labour saving: The new drip irrigation system has reduced labour requirements on this property by about 15% (1 person).

Crop inputs: Each system (flood, drip) receives 10 tonnes/ha/year of animal manure (pig effluent/slurry) from the on-farm piggery as well as 200 kg/ha of anhydrous ammonia. Nitrogen inputs are not reduced on the drip system, but are able to be applied over time in line with crop requirements over the cropping season. Generally, 70% is applied up-front, and the rest as required.

There is also no difference in the application of crop sprays (pesticides, defoliants) in the flood and drip irrigation systems on this property. Overall requirements for herbicides and insecticides have been minimised by planting GM (Bollgard, RoundUp Ready) cotton. Gypsum has been applied (5 tonne/ha every 4 years) to counteract the effects of the saline bore water. The only difference is that the rodenticide Mouse-off (0.5 kg/ha) is applied between crops on the drip cropping systems to minimise damage to the trickle tape.

Climate change: Increasing water scarcity will necessitate more efficient management of available water. Climate forecasts (SOI) are not used, but irrigation is held off if rain is forecast to avoid overwatering.

Water trading: Water trading has not been considered, nor would price be a factor influencing any decision to trade. A major factor for this property is that trading is physically not currently possible for disconnected water resources.

Case study 4: Vegetable (lettuce) Farm, Lockyer Valley, south-eastern Queensland

Farm description and parameter estimation

This is an 80 ha irrigated horticultural cropping farm in the Lockyer Valley, south-eastern Queensland. Seasonal vegetables (lettuce, broccoli, cauliflower) are grown through winter, and cover crops of barley, wheat and/or oats are grown through summer (rain-fed, not irrigated). The soil type is a sandy loam, and the irrigation water source is groundwater only, with the aquifer fed by the adjacent creek. Access to groundwater depends on availability, and there is no allocation on quantity. Water use in the local area is metered and charged by volume of usage. Irrigation is by drip (trickle) irrigation, with distribution to paddocks by pipe. In a normal irrigation season (2 vegetable crops) this farm relies on 1.2 to 2.5 ML/hectare of water per irrigated crop, with annual usage of about 5ML/ha for vegetables.

Property development: This farm was originally irrigated by overhead sprinklers (manual shift). Since 2004, the entire property has been converted, in 2 hectare blocks, to a drip irrigation system. The change from overhead to trickle was driven by water scarcity and the need to improve water use efficiency, but water savings have not been the only benefit. Improved soil health, improved crop health, increased yield, ease of management and economies of scale were all listed as additional advantages of the new irrigation system.

Rainfall patterns in this area can be highly variable, and water scarcity is a significant concern. Groundwater access has become progressively worse with recurrent drought since 1990 (at times, down to ~5% of total water availability, or around 22.5 ML/hr). Additional costs are incurred in pumping water when potential supply is limited; pumps need to be adjusted down and run less efficiently, and may need to run 24 hours a day. In addition, low pumping pressures under these conditions mean that water must be pumped into a dam, then repumped to deliver water at the pressure required (90 ML/hr) for the drip system.

The adoption of the trickle system has enabled this farm to irrigate 20 ha using the same amount of water previously needed to irrigate 8 ha with overhead. Water savings are dependent on soil type; the ~50% water savings achieved on this property have not been realised on other (leased) properties (e.g., on the eastern Darling Downs) where soil types are heavier.

Cropping system: Farming is on an annual rotational basis, with winter vegetable cropping and summer cover crops (as described above). Harvesting is determined by demand and market prices.

Planting and irrigation are in 2 hectare blocks, with permanent traffic 'marks'. Permanent tracking means a loss of 10% of soil; however this reduces soil compaction and has significant benefits in terms of soil health. Trickle tape is retrieved after each crop and re-used up to 5 times *('with experience, we are getting better at it all the time'*) within a cropping season, but replaced each year.

Technology adoption: Principle drivers for adoption of drip irrigation technology were stated as more efficient water use, improved crop and soil health, increased yields, ease of management, and economic profit. Barriers to adoption were seen as cost, with an initial outlay of $10,000 per 2 ha block ($5,000/ha) and annual replacement costs of $50,000 ($625/ha), as well as the limits of the technology (can only pump ~130 m before losing pressure). No significant problems have been encountered with the use of this technology. The drip system on this farm is now fully-automated and centrally-controlled.

Enviroscan meters are used to gain an understanding of how quickly water moves through the soil profile. These are used predominantly as a learning and planning tool, rather than for day-to-day irrigation scheduling; with up to 20 plantings at one time, it would be very expensive to install a meter in every block, as well as time-consuming to interpret all the information.

***Crop production*:** Production benefits are seen in terms of increased yields and improved quality under the trickle irrigation system. Increased productivity is difficult to quantify as harvesting is based on market demand, and quantified on a per head basis. However, further investigation and discussion with Dr. Craig Henderson from DEEDI indicated that this farm yields about 3775 cartons (12 head per carton, with an average weight of about 825 gm). In addition to yield benefits, there are potentially significant benefits in terms of quality. In overhead systems, mildews can reduce yield by up to 60% when there is a lot of rain due to a high level of residual mildews present in the crop. Under drip irrigation, there is generally very little leaf wetness, hence few mildews present in the crop, and yield reduction in wet weather may be closer to 10%.

***Labour saving*:** The old hand shift sprinkler system required 5 to 6 full time employees to operate. This was significantly reduced as the drip system was installed throughout, although 2 full-time employees were still required to turn taps on and off in each irrigation block. This has been further reduced with the system now fully-automated and centrally-controlled. In addition, the complexity of tasks has been reduced with, for example, the ability to fertilise while irrigating (fertigate).

***Crop inputs*:** The drip system allows significant flexibility and multi-tasking. With the completely automated system, each 2 ha block is watered for 1.5 hours per week and the entire farm can now be watered in a single day, This allows the flexibility to wait if rain is predicted, but to water as required if rain doesn't eventuate. With the old hand shift system, watering was continuous as the system had to be kept moving around the farm.

Regular soil testing is conducted on average once every 3 years. Fertiliser use has increased under the drip system, but with changes in fertiliser technology over time, it was expected that use would also have increased under the old sprinkler systems as well. Despite this, fertiliser efficiency is greater with trickle than sprinkler irrigation systems. Liquid fertilisers are now applied through the irrigation system (fertigation) in regular quantities adjusted to crop requirements over time; the old sprinkler system required the application of granular fertilisers, usually in 2 applications, which resulted in more leaching over time.

There has been no difference in herbicide or insecticide use. Crops are checked twice a week and decisions about insecticides and fungicides are made as required.

Cultivation has been reduced under the new system, however fuel is a relatively low proportion of cropping costs, and as a result close tabs are not kept on fuel usage. It was expected that energy use would be reduced under the trickle system, with less water applied and also lower pressure required for application than the former sprinkler system.

***Soil health*:** Significant soil health benefits (in terms of limited compaction) are associated with the permanent tracking system adopted in conjunction with the drip irrigation system.

***Climate change*:** With increasing water scarcity, the value of water can only increase, necessitating more efficient management of available water.

Water trading: Water trading is not conducted on the case study farm, but is on other leased farms, with landlords purchasing water on the temporary transfer market from neighbours. This was viewed as a poor system from a vegetable cropping perspective, where 100% water security is needed; permanent transfers would be much preferred.

Case Study 5: Pasture-cropping (lucerne, oats), southern Darling Downs, southern Queensland

Farm description and parameter estimation

This farm is a 1750 acre mixed irrigated/dryland lucerne/grain cropping and feedlot enterprise on the eastern Darling Downs, southern Queensland, with part of the cropping area leased to a horticultural enterprise (onions). Of the total cropped area, 650 acres is irrigable and 100 acres is dryland. Cropping soil types are black alluvium (creek flats) and sandy loam (ridges). Irrigation water sources on this farm are from harvested streamflow (nominal volumetric entitlements, allocated volumes) and overland flows (licensed volumetric limits), and groundwater extraction (nominal volumetric entitlements, allocated volumes), although little groundwater (40% of allocation) is used due to diminishing quality. Harvested overland flow water is stored in on-farm storages (authorised storage capacity). This farm relies on 8 to 16 ML/ha per annum of water for irrigation, applied by sprinkler (centre-pivot, roll-line) irrigation systems. Water is distributed to irrigation paddocks by pipe.

Property development: Irrigation on this property commenced 12 to 14 years ago with the installation of roll-line sprinkler systems, but has been progressively converted to centre-pivots over the last 10 years. There are currently 620 acres under centre-pivot (x 5) and 30 acres under roll-line sprinkler systems. Further areas on the lighter (sandy loam) ridge country are currently being developed for another 3 centre-pivot systems to expand the leased horticultural area.

Water reliability is viewed as a serious problem, and water security has been a high priority (‘*you need to invest in things that are in short supply*’). The irrigation farming system on this property is currently designed to cope with the worst case scenario in terms of water availability, based on analysis of 120 years of climate records from the Hermitage research station near Warwick. Total off-stream water storage capacity on this property is 1.0 GL, and the in-stream weir ponds up to 1.7 GL. Sprinkler irrigation systems were adopted to increase the efficiency of water use on the farm, though the actual WUE of these is unknown. Water savings have enabled an increase in the irrigated cropping area on this farm. Centre-pivot systems can apply approximately 55 mm/week at peak evaporation, and use approximately 50% of the water used by the older roll-line sprinkler system.

Cropping system: To some extent, farming is on a set rotation, with lucerne grown for 3 years, followed by either a grain (maize, sorghum, wheat) or pasture crop (oats). Lucerne is cut for hay and/or grazed if the crop is poor. On the lighter country, onions are grown on a 2 year rotation, followed by 2 years of forage crop. However, in effect the cropping program is based on the quantity of water in storage (‘*we farm the water*’), and commercial judgements are made on that basis.

Technology adoption: Principle drivers for adoption of centre-pivot sprinkler irrigation technology were stated as labour-saving, increased efficiency, low cost of application/maintenance, reliability and ease of management. Full-circle centre-pivot systems were preferred; earlier lateral-move and part-circle centre-pivot systems used were found to be problematic as they needed to be 'walked back' and the time this took caused problems when a crop required water. While irrigation is on the circle, planting is still generally done on the square with planting rates adjusted by GPS (tractors are all GPS auto-steer).

Barriers to adoption of new irrigation technologies include time, outlay costs (e.g., $80-90,000 per centre-pivot, and $2,470 to $3,700/ha installed) and lack of water plan security. ('*Each new policy initiative, from the WAMP to the federal Murray-Darling plan, has involved cuts to water allocations and security*.'). Permanent drip irrigation is not seen as a feasible option on the black soils because of their self-mulching characteristics; however temporary tape is considered an option which could be easily installed, if needed, on the horticulture pivots on the lighter country.

Electronic probes and manual soil probes are used to monitor soil moisture, enabling water to be applied at the best time based on the soil water profile ('deficit irrigation'). This is critical on the heavier black soil types ('*need to deficit irrigate or waste it*'), but if well managed it is possible to achieve a 30% better crop with 30% less water ('*the 30% rule*'). Even greater efficiencies can be achieved on lighter soil types where deficit irrigation can increase profits by 60 - 80%.

The farm is highly monitored ('*if you can't measure it, you can't manage it*') and increasingly automated. There are on-site meters at all creek pumps and pivots, and plans to be able to monitor and operate these remotely, although this is currently limited by the technology (e.g., low speed broadband) that's currently available at an economic rate. '*Farming in water-poor regions is generational, with incremental long-term gains*.'

Crop production: Lucerne is the most profitable crop grown, but it is a high water user. The crop is cut for hay, producing some 6.5 tonnes/ha/cut (about 3 cut per year) under centre-pivot sprinkler irrigation; this is 1.5 to 2 tonnes/cut more than that grown under the older roll-line irrigation system. The equivalent water productivity for these systems is 2.44 tonnes/ML for the centre-pivot system and 0.93 tonnes/ML for the roll-line system; centre-pivot water use is 8 ML/ha compared to 16 ML/ha for the roll-line system. On these values, yield improvement due to the adoption of the centre-pivot irrigation system is approximately 45% per hectare and 170% per ML of water compared with yields for the roll-line irrigation system. Gross margins on lucerne grown under the centre-pivot system and cut for hay are estimated at $4,940/ha and about $620/ML.

Benefits in terms of horticultural productivity are more difficult to measure, as these are essentially market-driven. While profits can be significant, the level of financial risk is also high. For example, in two consecutive years, 40.5 ha of irrigated onions yielded 49,400 kg/ha on 3.3 ML/ha and 4.3 ML/ha of water (i.e., 15.0 and 11.5 tonne/ML, respectively). However, price variation meant that gross margins ranged from $54,340/ha to $19,760/ha (i.e., $1.10/kg to $0.40/kg or $16,467/ML to $4,595/ML)

Labour saving: The new irrigation technologies have reduced labour requirements on this property by about 100 man-days/year. However, concern was expressed about issues associated with retaining trained staff who, once they are competent in the use of high-tech equipment such as GPS auto-steer tractors, have moved on to employment in the mines.

In terms of labour costs, comparison was provided for the different irrigation systems under horticulture:

- hand-shift sprinkler systems: \$3-500/acre/crop;
- drip-tape trickle systems: \$300/acre/crop (\$100 to lay, \$100 to retrieve); and
- pivot sprinkler systems: \$100/acre/crop (maximum)

Crop inputs: Each irrigation and cropping system receives small inputs of effluent (estimated at 10 ML/year) from the on-farm feedlot which runs into the storage dam from which irrigation water is drawn for distribution around the farm. No additional fertiliser is applied, though lucerne provides 2-3 yrs benefit in terms of Nitrogen input ('*land is something to stand the crop on*' and '*centre-pivot is broadacre hydroponics: sunlight + water = profits*'). Both systems receive 2.5 tonnes/ha of gypsum every 6 years.

There is no difference in the application of crop sprays (herbicides) for the two irrigation systems used on this farm, and overall requirements for herbicides are minimal (1 l/ha pre-planting, and 0.2 l/ha three times a year over the life of the crop). The owner describes himself as a percentage farmer ('*90% is good* enough'), using temporary fencing, farming by contract where possible and not too concerned about weeds. Lucerne is grown because herbicides can be used to control grass weeds, and because GMO crops (e.g., corn) cannot be grown. This system requires minimal crop cultivation and management ('*we only manage if there's a problem*').

There was concern expressed about the quantity of energy used on the farm, largely associated with the irrigated cropping components ('*Everyone is currently focused on volumetric issues in terms of water use. However, this focus will change in the next 10-20 years; the energy factor will be critical into the future.*'). Energy use has been reduced by an estimated 15% with the adoption of the centre-pivot irrigation system and conversion to electric pumps. Reduced water requirements hence pumping also enabled a change to pumping at night and on weekends when tariffs are lower (from \$0.15/KW to \$0.11/KW; a saving of \$0.04/KW).

Climate change: Increasing water scarcity will necessitate more efficient management of available water. On this farm, climate forecasts (SOI) are noted as these indicate the probability of water harvesting events; commercial decisions are based on a combination of water availability and climate forecasts (the probability of rain). The property is essentially set up for climate change. It was felt that there may be little change in the overall amount of rainfall, but that its distribution and intensity may change. This property is set-up to enable the maximum-allowable capture and storage of high-intensity rain.

Water trading: Water trading is not considered an attractive option for this enterprise ('*never sell your best asset; you need to use it to create additional income*'). Concern was expressed about the one-size fits all approach of the water-trading market at present; it was felt that there should be greater appreciation of the value of water associated with where it sits in the catchment ('*1 ML here is not the same everywhere*'). For example, a volume of water transferred from the eastern Downs, where pan evaporation is 1.4 m, would be significantly diminished in value if it was transferred to an area such as Cubby, where pan evaporation is >2.4 m. In addition, 1 ML water on the eastern Downs has higher value than 1 ML water further from markets.