Beyond Modern Land Drainage

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Abstract

Modern Land Drainage implies making drainage environmentally sustainable which includes enhanced water balance assessments at regional and field scale (incl. a detailed look at water movement on the rootzone), prevent excess water except for leaching salts, support ecological water requirements, and then if any access water remains design a drainage system. The less water is mobilised through our agricultural lands, the better the quality of water will remain. No matter how efficiently our crops are watered, sooner or later we need to have a well-functioning drainage system for complete in-field water management. Under natural conditions, i.e. in areas with rainfall surplus and no irrigation system, drainage is considered when causing waterlogging that restricts crop growth. Salinisation of the land, i.e. the accumulation of salts in the upper layers of the soil occurs naturally in coastal areas but can be a secondary effect of waterlogging. In all cases the absence of a sustained seasonal net downward water movement through the rootzone is generally the reason for salinisation. Beyond modern land drainage includes various approaches to assessment, prevention of waterlogging and salinity problems, considers the water-food-energy nexus approach and gives due attention to ecological and economic considerations (Triple bottom Line, TBL) for more sustainable results. However, the most important consideration to be included in drainage system design is the consideration of Cause and Effect. Waterlogging and salinity problems are the Effect of something that is occurring most likely upstream; the Cause. Theories of drainage design have been well developed and with powerful computing now available at the desktop at affordable prices, many solutions to a drainage issue can be considered that include controlling the amount of water drained, reused, and, how and where best to control drainage water quality. Ready access to satellite imagery, new and enhanced existing computer models to simulate land inundation and the recent advance in the use of drones with cameras (quad copters and the like) provide an opportunity to enhance integrated water resource, imbedded drainage design. Regardless of these technological advances nothing beats going out when it rains to assess what is really happening in the field. A holistic approach to agricultural drainage is described that includes steps to successful stakeholder involvement from beginning to end, from farm to fork and from farmer to minister. The approach considers measures at the location of the Cause first and then at the location of the Effect.

Introduction

Modern Land Drainage (MLD) is an extended approach to the traditional drainage design methods for rain fed agriculture in the humid temperate zone. It includes and extensive consideration of salinity control of irrigated land in (semi-) arid zones, drainage of rice land in the humid tropics and advocates controlled drainage in the framework of integrated water resources management (IWRM). Institutional, management and maintenance are included as well as the mitigation of adverse impacts of drainage interventions on the environment. Beyond Modern Land Drainage considers the Triple Bottom Line (TBL), the triangle that considers interactions between social, environmental (or ecological) and financial aspects and extents it to consideration of drainage within the Water-Food-Energy Nexus (Vlotman 2014).

At the ninth International Drainage Workshop (IDW9, 2003) in Utrecht, the Netherlands, drainage was placed firmly in the realm of Integrated Water Resources Management (IWRM). At IDW10 held in Finland and Latvia in 2008 it was mentioned that drainage is an important driver for sustainable outcomes and the three main areas of indicators for the need for drainage in the framework of sustainable IWRM were given as (Vlotman 2008):

1. an aging water supply system and infrastructure that supports economic development,
2. the perceived changes in regional climates (i.e. the Climate Change bandwagon), whether caused by anthropogenic influence or whether part of a natural cycle, and
3. the increased attention for sustainable physical environments.

At the 11th ICID International Drainage Workshop on Agricultural Drainage Needs and Future Priorities in Cairo, Egypt from September 23 to 27, 2012, the discussions centred around how to make agricultural production possible and more profitable. Agricultural drainage is part of integrated land and water resources management where environmental aspects play an important role; the impact of agricultural drainage on crop productivity and environmental aspects and advances to address these issue were elaborated (IDW11 2012).

The theme of the12th International Drainage Workshop (IDW), 23-26 June 2014, St. Petersburg, Russia was: Drainage on Waterlogged Agricultural Areas. Sub-topics were: (a) New equipment and modern technology drainage construction in wetlands; (b) Efficiency of the use of reclaimed land and socio-economic aspects of the use of reclaimed land; (c) Drainage design and methods of calculating; (d) Advanced training of specialists: constructors and engineers in the field of drainage systems management and operation; (e) An integrated approach to the management of drainage and environmental protection; (f) Using reclaimed land for agricultural purposes; and (g) History of the drainage system development. The proceedings do not contain a summary of the discussions of each section.

At IDW13, a new paradigm for sustainable, integrated, water resources management is presented that has been emerging from international conferences around the world. Its most succinct description is 'the water-food-energy nexus (WFEN) for a green economy'. The water, food and energy nexus aims at the most efficient, best practice principles applied throughout the full food supply chain. This includes consideration of reducing wastage of the food for various reasons in the supply chain. Food wastage equates on average to 243 litres of water a day/person in the food they throw away, which is 1.5 times the daily water use per person (Vlotman and Ballard, 2014). The concepts of virtual water and water footprint can help in identifying opportunities to save water by targeting reduction of wastage of food that has the highest virtual water content. Energy efficiency occurs when we consume where we grow, so do not transport food unnecessarily. Green economy aims at achieving the optimised supply chain objectives in a manner that espouses the sustainability principle, gives due attention to environmental concerns and helps with eradication of poverty and hunger.

Artificial and natural drainage systems are an essential part of the water management system; in fact many systems would not be sustainable without it. For instance, managing salinity and waterlogging requires artificial or natural drainage to be in place. However, it is probably needed only a few times per year if irrigation is applied efficiently resulting in minimum leaching requirements.

Over the years it has become clear from worldwide experiences that economics and technical expertise are not the only key drivers of drainage development and that care for the natural physical and social/cultural environment will enhance the likelihood of sustainable water management and sustainable drainage systems.

The drivers of sustainable environments are, amongst others, the Key Performance Indicators (KPIs) of Triple Bottom Line (TBL) frameworks that inform us how well we are doing. These KPIs are either oriented towards internal business performance or towards external impacts of water management organisations, incl. business by government departments. It is important to keep the internal and external KPIs separate such that mission, strategies and operational objectives of the organisation that is responsible for the drainage system are clear in the mind of all stakeholders. Drainage environmental KPIs are related to salinity, waterlogging and water quality while many others relate to the IWRM more generally.

The drainage system design process

The steps in traditional land drainage design are identification of the problem, reconnaissance or a pre-feasibility stage, then the actual feasibility stage followed by the detailed design stage (Smedema et al. 2004). Operation and Maintenance processes come into play after the construction and commissioning of the drainage system. Beyond modern land drainage design includes considerable stakeholder involvement right from inception to eventual ownership of the systems, and also includes remote sensing technologies in the early stages and post construction with due regard to economics and environmental/ecological considerations.

Beyond Modern Land Drainage starts with a process of stakeholder involvement. The process was elaborated in a background paper at the ICID meetings in Chiang Mia, Thailand and the following are suggested (after Ardakanian et al. 2016):

- Carry-out an assessment of existing institutional arrangements with all potential stakeholders of the area under consideration for water management interventions
- Ask stakeholders what needs to be established in order to become more involved (gap analysis)
- Identify the challenges & demands of the stakeholders
- Identify the need for continuity of participation and support capacity building keeping in mind the operation, management and maintenance needs of the future
- Identify the need for political commitment, innovation and advocacy for involvement.

Vlotman and Ballard (2014, 2016) included two more aspects:

- Energy efficiency. This includes considerations such as switching from high pressure sprinkler systems to low sprinkler pressures systems, gravity drainage instead of pumped drainage, consume food where it is produced, avoid growing food at location A, transport it to B for wholesale and then back again to A for retail; this will safe oil (truck and rail transport), gas (heating and cooling) and electricity (electric train transport, cooling needs), re-introduce seasonality in the availability of foods, and
- Reduce food wastage, i.e. reduce the loss of imbedded or virtual water. Do not buy more food than needed, recycle food via Foodshare (Foodbank, 2013), Fareshare (2013) and retail at farmer markets (Vlotman and Ballard 2014). This will use food more effectively and efficiently without wasting it and at the same time save virtual water, which then allows it to be an actual water savings higher up in the food and water supply chains.

These latter two aspects were cast in the water-food energy nexus to assist the balancing of these elements in the triple bottom line framework with irrigation and drainage systems, Vlotman and Ballard (2014).

To achieve active stakeholder involvement a planned process will need to be executed (MDBA 2015):

- Assessment of state of institutional development at all levels;
- Needs assessment;
- Plan development reflecting:
  - Who you will engage with;
  - Why you will engage them;
  - Why they will want to engage with you;
  - How you will engage them;
  - When you will engage them, and how you will monitor and evaluate your engagement approach?

The key for involvement of stakeholders in irrigation and drainage system operation, management and maintenance (OMM) is the central question: what is in it for me? Incentives do not necessarily need to be economic in nature. They can be improvement in lifestyle, improvements in physical environment and in general improvement in social well-being. Hence, in order to involve stakeholders in water management, incl. irrigation, drainage and environmental watering, it is essential to find out first in what type of TBL environment they operate and what their needs are. It is not just involvement in water management but consideration of all aspects of being successful (i.e. all TBL elements and all water-food-energy nexus considerations, WFEN).

All stakeholders from farmer to system operator to top level regional and national government staff need to have a clear understanding of the potential benefits of being involved and they need assurance that those benefits are sustainable. Stakeholder engagement is a planned process with the specific purpose of working across organisations, stakeholders and communities to shape the decisions and actions of the members of the community, the stakeholders and the organisations involved. Typical questions to be asked in planning for the involvement of water managers at all levels, including foremost farmers, are:

- What issues do you face in being successful in your (water operation, management and maintenance) enterprise/organisation?
- Do you consider all TBL aspects for the design and future operations?
- Are you willing to share water with the environment/ecology?
- What additional knowledge, skills and information do you need to make an informed decision?

These questions will generate discussions, anger, trepidation, excitement and raise a range of socio-economic issues that should not be ignored and are essential to consider for successful involvement of stakeholders in the design process of drainage system and the eventual successful OMM of the system.

Design

Although traditionally drainage design evolves around rainfall intensities, in particularly in the temperate climate zones, this is not always the case and it is changing rapidly. In irrigated areas the efficiency of the water delivery system determines the need for drainage (Table 1). In drier climate zones flooding is caused by runoff from upstream areas congregating in the lower reaches of the catchment. The fact that the “problem” is caused upstream suggests a closer look at what is happening upstream. Should we re-forest certain areas, should we change land use (Baoa et al. 2017), should we built water and salt interception schemes? Fortunately recent advances in aerial photography with drones and advances in the use of satellite remote sensing applications will allow us to determine the need for drainage in more holistic ways than before. This will be described in further detail in the section on remote and robot reconnaissance.

Table 1 Efficiency of various irrigation methods

Method	Efficiency (%)	Remarks
Flood irrigation	50 - 85	New water management control technologies
Sprinkler irrigation	65 - 90	From high pressure to low pressure application
Trickle irrigation	75 - 95	Reliability, durability and water management
Sub-surface irrigation	50 - 95	Shallow soil management
Controlled drainage	50 - 85	Maintain and manage high water table as appropriate
State of the art water management	85 - 100	Soil moisture management and delivery system management combined

Traditionally (or, almost traditionally), design of drainage systems is supported by using a variety of water resource models (MIKE21, SWATRE, HEC-RAS, DUFLOW to name a few) and dedicated drainage models such as the various versions of DRAINMOD (Box 1), to investigate a variety of drainage rates under different weather and design arrangements (i.e. depth and spacing of drains). Modern Land Drainage (Smedema et al. 2004) gives a listing of websites to access these models which was current in 2003 and is a good starting point to investigate the latest in computer aided design. The models can include salinity levels and levels of other potentially toxic elements such as nitrogen, Biological and Chemical Oxygen Demand (BOD & COD), a variety of micro-organism, pesticides, etc. Many dedicated computer models exist for these situations.

Obtaining good topographical maps is essential for detailed design. A viable alternative during the reconnaissance stage of projects under consideration is the use of Google Earth, which now includes generation of surface elevations along selected lines, which could be proposed surface and sub-surface drains rather than the streams shown in Figure 1. Spatial software applications based on satellite imagery, aerial photography or drone imagery can also provide the exact extent of flooding, waterlogging (indirectly through observing the status of the vegetation) and salinity.

Box 1 Overview of the state of DRAINMOD models.

DRAINMOD based field and watershed scale models
http://www.bae.ncsu.edu/soil_water/drainmod/models.html accessed 5/11/16.
For details of references see the website.

The original DRAINMOD hydrology model has been modified to include sub-models on the fate and transport of nitrogen in the soil and salinity. The field hydrology and water quality models were also coupled with drainage network routing sub-models for watershed scale applications. Below are the models developed at the Biological and Agricultural Engineering Department at NCSU.
FLD&STRM (Konyha, 1989) - DRAINMOD based watershed scale Agricultural water management model.
DRAINLOB (McCarthy, 1990)- DRAINMOD based field scale forest hydrologic model.
DRAINMOD-S (Kandil, 1992)- DRAINMOD based field scale model for predicting salinity on arid/semi-arid lands.
DRAINWAT (Amatya, 1993) - DRAINLOB/FLD&STRM based watershed scale forest hydrologic model.
DRAINMOD-N (Breve, 1994) - DRAINMOD based field scale model for predicting Nitrogen from agricultural lands.
DRAINMOD-NII (Youssef, 2003) - DRAINMOD based field scale model for predicting Nitrogen
DRAINMOD-DUFLOW (Fernandez et al, 1997) - DRAINMOD field scale model linked to the Dutch model DUFLOW - a one-dimensional drainage canal routing model and water quality model based on the solution to the St Venant equation and ADR equation.
WATGIS (Fernandez et al, 1999) - A GIS-based lumped parameter watershed scale hydrology and water quality model. DRAINMOD and DRAINMOD-N models coupled with a delivery ratio routine to route drainage water and nutrients to the watershed outlet.
DRAINMOD-GIS (Fernandez et al, 2000) - A GIS-based lumped parameter watershed scale hydrology and water quality model. DRAINMOD/DRAINMOD-N models coupled with a simplified water and nutrient fate and transport sub-models.
DRAINMOD-W (Fernandez et al, 2001) - A watershed scale model based on DRAINMOD and DRAINMOD-N field scale sub-models with a finite difference canal routing model and a finite element solute transport sub-model.

The FAO Irrigation and Drainage Paper no 62 (van der Molen et al. 2007) on guidelines and computer programs for the planning and design of land drainage system is one of the latest readily available publications on land drainage design but considers minimal attention to stakeholders (farmers only) and environment is described in an eleven line paragraph. For the latest in environmental design and for examples of the use of the web to view live river data see the Murray-Darling Basin Authority website (http://www.mdba.gov.au) and navigate to the "publications" and "live river data" sections (http://livedata.mdba.gov.au/system-view). For selected locations in the system overview data such as water levels, river and channel flows, reservoir storage levels and reservoir releases, rainfall, water temperature, dissolved oxygen levels and salinity levels are given. This type of information will be very helpful during the reconnaissance and OMM stages in the life cycle of drainage systems and how they interact in the broader integrated water resource management system.

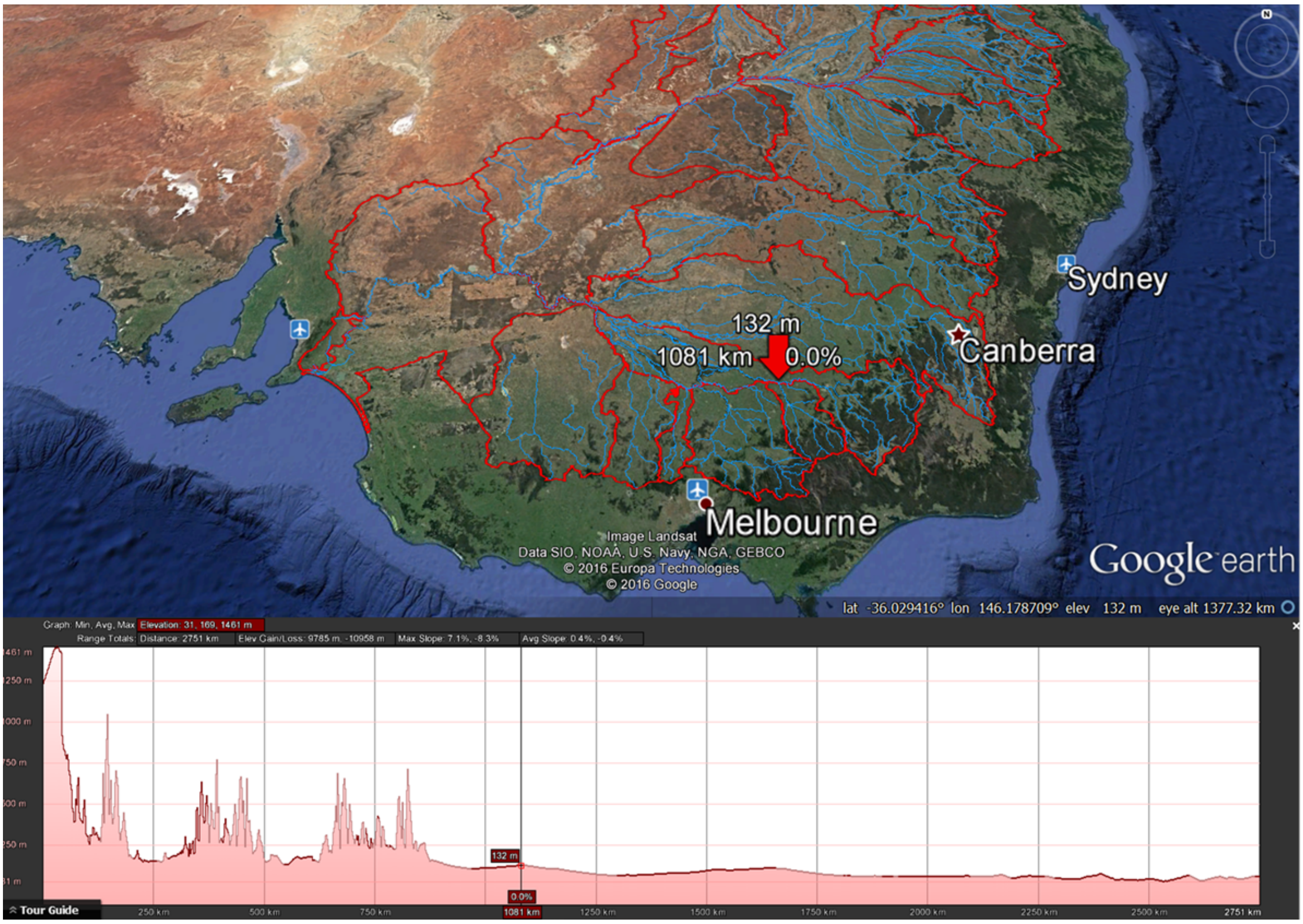

Figure 1 Screen dump of Google Earth map with basin regions boundaries (in red; i.e. catchment boundaries) and rivers in blue.

A right-hand click on top of a river line will produce an elevation profile as shown. Naturally the river will not go uphill as is shown in the profile here; this however is a scale and location of the line representing the stream on top of the Google Earth map which at this scale is highly inaccurate (accessed December 2016). The red arrow in the map will move along the river line when the vertical line in the elevation profile is moved. The elevation heights are in meter, but care should be taken to check the datum of the elevation used.

A rather interesting design process is proposed by Tuohy et al. 2016. The method is based on a new visual soil assessment method whereby an approximation of the permeability of specific soil horizons is made using seven indicators (water seepage, pan layers, texture, porosity, consistence, stone content and root development) to provide a basis for the design of a site-specific drainage system. The incentive was the ability to design a suitable system for each of the stakeholders at the lowest possible costs.

In the next section additional innovations are described that are considered beyond MLD in the reconnaissance, analysis, and design stages of drainage systems, including consideration of new materials and equipment available in today's environments and markets.

Remote and Robot Reconnaissance

Similar to involving stakeholders from the beginning to the end, a thorough technical analysis of the condition at, up and downstream of the intended drainage system is essential. The advances in remote sensing techniques and the availability of these services as well as the skills of our stakeholders allow a sophisticated process to be included in the reconnaissance stage of the design process. These processes may actually lead to the conclusion that drainage is not necessary if other, potential cheaper solutions high or lower in the water management system show promise that will negate the need for drainage, or, show means of controlling water quality at downstream locations.

The continued advances in remote sensing in the last couple of decades (Figure 2) have been significant and will continue to evolve at a rapid pace when more satellites are launched (Landsat, IKONOS, MODIS, SPOT, QuickBird, WorldView, RapidEye, etc.). Access to the raw outputs of Landsat imagery is easy via the web. More advanced outputs are commercially available and can include those from other platforms such as aerial photography and drones. Many government agencies and private companies are developing tools to help with accessing and assessing the data available via the web and internal computer network systems. This is a far cry from the good old days when draftsmen prepared drawings on tracing paper; then to be printed; the smells of ammonia filling your nose; something un-imaginable with today's attention to Occupation Health and Safety procedures (OHS).

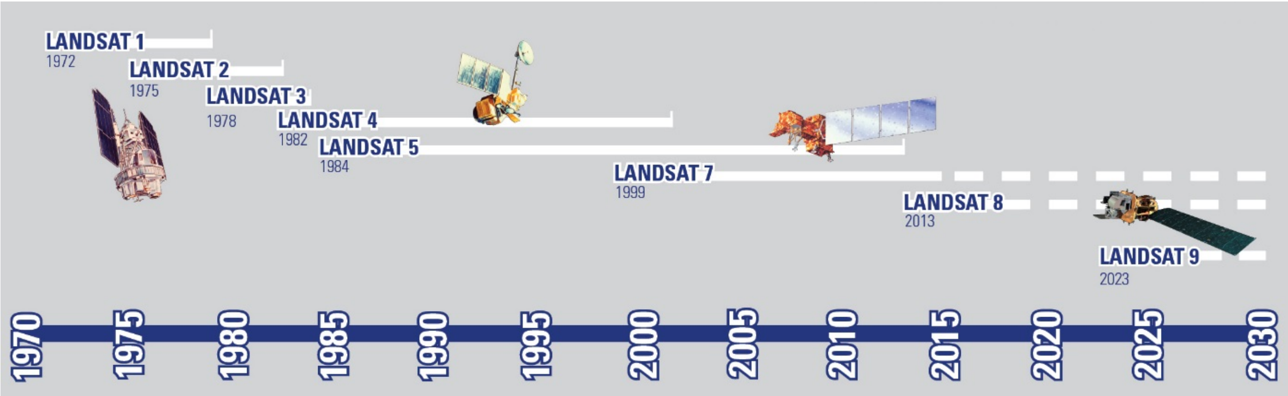

Figure 2 Overview of Landsat satellites past, present and future.

Agencies in the US and Australia now make water observation from space (WOfS) maps available (US Landsat web, http://landsat.usgs.gov, and WOfS web from Geoscience Australia, www.ga.gov.au). These maps are used to inform flood inundation modelling and mapping which allows us to assess the extent and duration of flooding at certain flow rates from low overbank flows (Figure 3) that occur on a regular basis (several times a year) to events that occur only 1 in 50 or 1 in 100 years. As Figure 2 shows the remote sensing information is readily available from 1972 and one will find that in these last 40 years there is a good likelihood that events that occur 1 in every 50 or more years are covered.

The emergence of drones with cameras at retail outlets, rather than the sophisticated multi-million dollar drones used by the military has opened a whole new avenue of reconnaissance. Combined with traditional aerial surveys, albeit with far more sophisticated equipment such as cameras used on satellites with various band widths that identify plant health and water in the landscape than in the past, we now can study flood events as they occur.

Reconnaissance during operation, management and maintenance (OMM) stage of the life cycle of a drainage system could be with the use of swarm farm robots for precision application and control of drainage water quality (Figure 4). The idea is that farmers instead of large tractors and sprayers use a swarm of autonomous, collision-avoiding robots that can spray with accuracy and in the right quantity when via GPS and satellite linkage other farm inputs such as soil type, moisture content, etc. are fed into the software controlling the swarm bots and adjusting the intensity and concentration of the spraying. Clearly a variety of sensors can be added or built-in the swarm bot and salinity (think of EM38 salinity survey technologies, Vlotman 2000), soil moisture, temperature of the soil and a variety of chemical assessments with probes drawn through the top layers of the root zone can be performed.

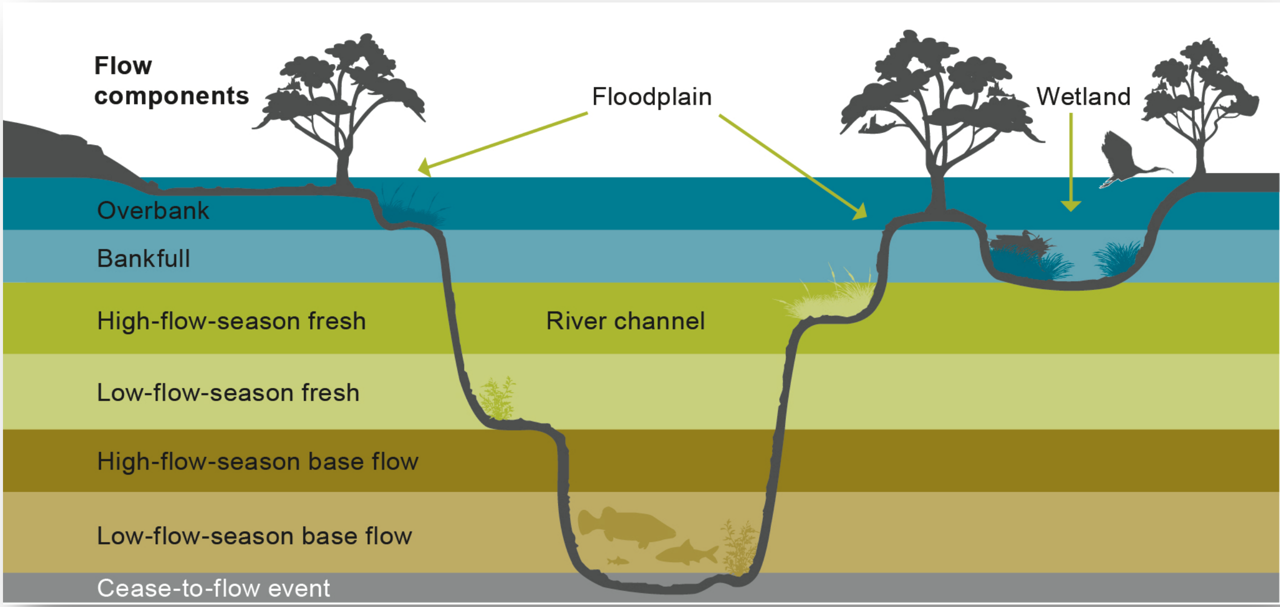

Figure 3 Schematic of flow types, incl. overbank flow (MDBA 2011)

Figure 4 Swarmfarm robots in action (www.swarmfarm.com).

Linking hydrological data with remote sensing data, whether flood extent, vegetation type or biological occurrence (bird surveys, fish numbers) can result in outputs such as shown in Figure 5 showing the area of flood plain grassland covered for a range of flow rates and Figure 6 showing aerial survey of the number of birds observed in various wetlands and the area of wetland at the time of fly-over. Data collected as shown in Figure 4 and 5 can be used in design and OMM processes to determine the amount of irrigation water needed, drainage water to be removed or localised leaching of salts to be planned. Bird breeding events can be analysed in more detail and may actually be planned by giving additional water to certain wetlands.

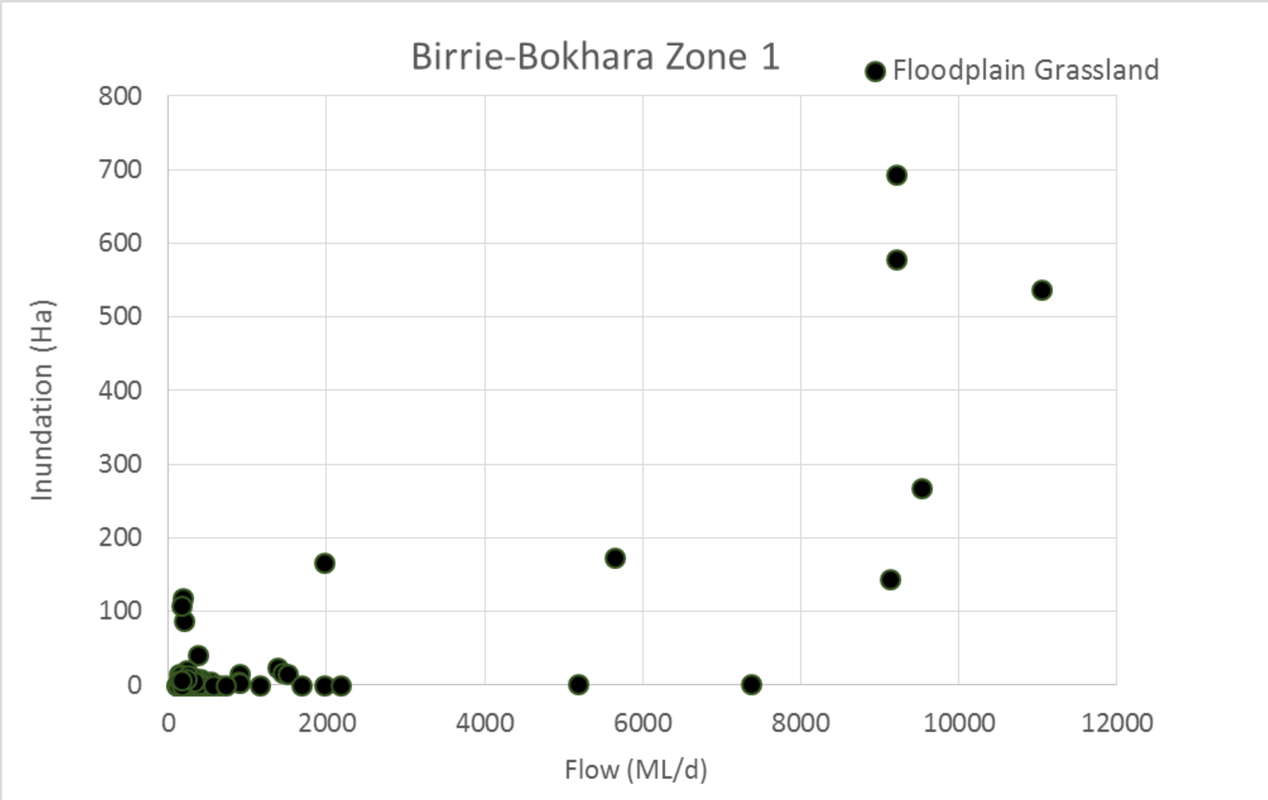

Figure 5 Example of relating a vegetation type to flood extent (Weldrake et al. 2016).

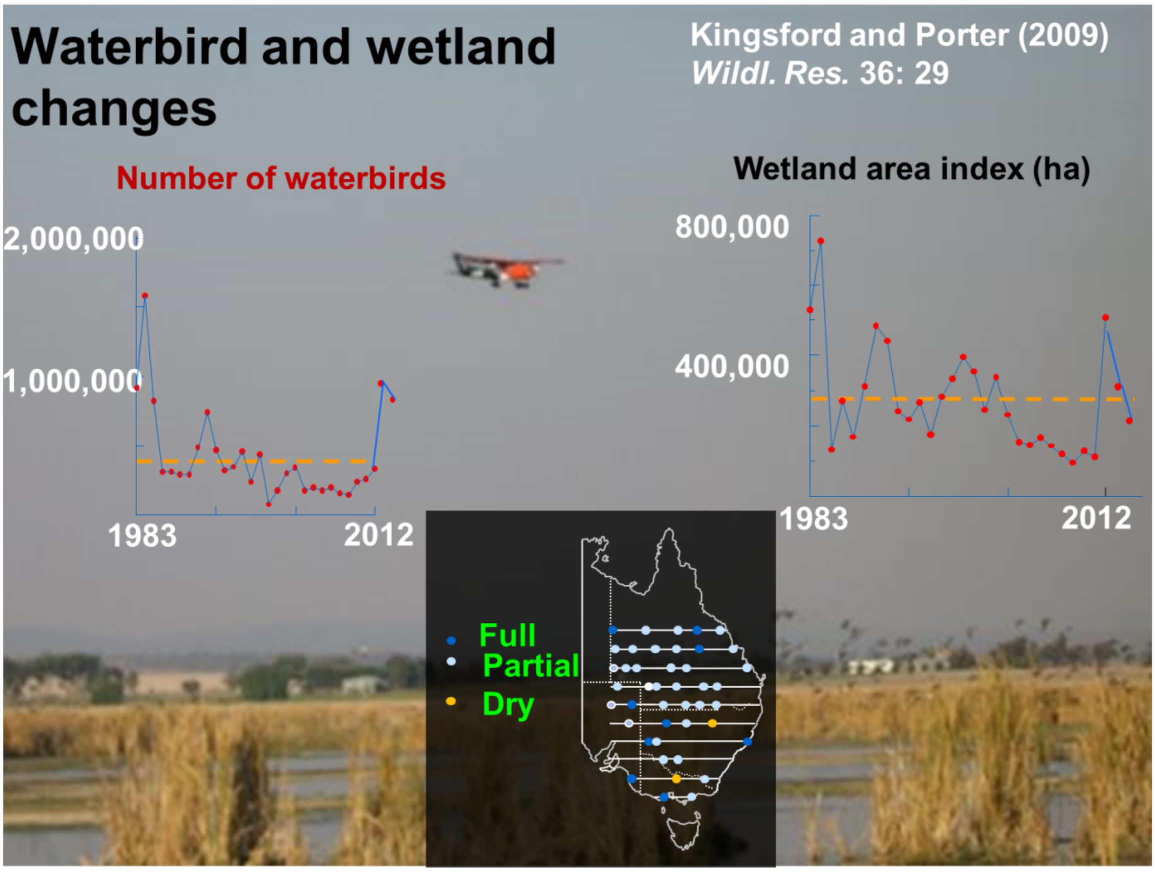

Figure 6 Number of Water birds and Wetland area index (Kingsford and Porter, 2009).

The applications of remote reconnaissance described above are only the tip of the proverbial iceberg of possibilities and opportunities to develop and advance these technologies further.

Final comments and conclusions

Beyond Modern Land Drainage espouses the use of new materials. For instance the Capiphone drain (www.greenability.com.au) uses the capillary action of the drain to both drain and supply water to the root zone; a new form of controlled drainage and irrigation. This type of drainage is also known as wick drainage although this is different in its applications and configurations (Koerner 1994, Vlotman et al. 2000).

For water quality control prevention is the best solution and precision agriculture, including the type of application such as advocated by swarm farm robots are exiting new developments.

For salinity control we need to become a bit more innovative and think out of the box. For instance the farmer, which sees his/her land becoming increasing saline over time and looks at the government to provide solutions can actually do something him/herself. By taking part of the farm out of production and assuming (s)he has access to the same amount of water as before, (s)he can irrigate the remainder of the fields with adequate water, including meeting leaching requirements. It is important that in fields affected by salinity a net downward water movement through the root zone is maintained on seasonal basis! This assumes that the government cannot give more water due to a number of constraints, and assumes that the farmer can still make a living of the remainder of the farm. It may be that the farmer needs some financial support in the form of government guarantees of income, while he or she experiments with concentrating the water available to recover sections of the farm and make them salinity free.

Consider solutions that reduce the upward movement of water (and salts) in the root zone; can we cover the ground with plastic during part of the growing season and thus minimise direct soil water evaporation? Unfortunately in areas where plastic has been used in agriculture, the OMM is not very effective in removal of the plastic afterwards and severe visual and possibly ecological damage results.

A major change in paradigm in Modern Land Drainage design, construction and operation is that we not only concentrate on technical solutions, and not only consider the location of the problem, but take a much wider perspective in time, space, environment, ecology and stakeholder involvement. Look what can be done upstream of the location, look how a change in water management upstream can prevent the problem occurring downstream, look what alternatives there are for the farmer such as re-locate, train, re-skill and change job. If the solution is not found upstream look at minimising or eradicating the negative downstream impacts and turn them into opportunities to enhance water schemes everywhere.

Finally, in the foregoing a number of solutions were described to use the advances in science and technology combined with active stakeholder involvement from top to bottom and from beginning to … no not the end, but to the stage of Operation, Management and Maintenance (OMM). This is intended to make drainage design more effective and sustainable in the long-term. It is suggested that prevention is the solution to many problems and that a holistic approach such as advocated by Vlotman and Ballard (2014) in describing the water-food-energy nexus for a green economy is necessary for a sustainable triple bottom line development. It is also imperative that the scale of intervention is extended beyond the mere location of the drainage system and that by considering carefully what is happening upstream and downstream of the location, it may be concluded that other solutions to the problem are more effective and guarantee long-term success. There are many opportunities to save water, energy and food beyond the realm of consideration of a drainage system in isolation. The involvement of stakeholders from beginning to end, from farm to fork, from farmer to minister, and to preserve and maintain ecological environments in conjunction with food production is essential in the success of any endeavour including modern land drainage design. Beyond Modern Land Drainage strongly recommends to use a Cause and Effect approach;

first consider what can be done at the location of the Cause; this will reduce drainage water quantity and possibly improve drainage water quality, and then see what is still necessary at the location of the Effect; i.e. at the location of waterlogging, salinity and poor drainage water quality. Naturally, this should not stop the planner, in contradiction to what has just be suggested as the best approach, to treating the Effect first. It may be that treating the Cause first is a much longer process than treating the Effect. Hence, there is an argument for installing a drainage system first to prevent future waterlogging and start the local desalinisation of the soil profile. A the same time stakeholder engagement process as recommended above can be initiated to deal with the Cause of the problems. If we think of 10 – 15 years for implementing both remediation of the Effect (in the first couple of years) and the Cause (convincing all stakeholders 3 years, planning, design and construction another 5 years), then it probably can be shown that first treating the Effect and then the Cause is economically justifiable and more sustainable and socially acceptable (TBL) in the short- and long-term. For new drainage systems, not yet constructed, the Cause can be dealt with first possibly saving considerably on the cost of a drainage system to deal with the still potential effects of causes that cannot be included cost-effectively in the first place.

Beyond Modern Land Drainage design is using the latest science, technology and socio-economic insights and considers the interaction between water, energy and food production with the highest water and energy efficiencies for the best outcomes for all stakeholders in a green economy (Vlotman and Ballard 2014).

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