Monitoring On-Farm Water Storage use: From LIDAR to Multi-Source Remote Sensing

Chemin, Y.,[1] and Rabbani, U.,[2]
[1]International Water Management Institute, Pelawatte, Sri Lanka
[2]School of Environmental Sciences, Charles Sturt University, Wagga Wagga, NSW 2650, Australia

Abstract

Faced with unreliable rainfall patterns, Australian farmers have developed on-farm water storage (OFS) solutions over the drought years. Recent thinking in water policy under the Commonwealth government considers extending the Cap over surface water to OFS as they are not currently covered under the Cap and eluded the effective water policy arrangements across users and the states. A unified approach to Cap implementation involving water diversions from the river system, OFS and other direct diversions and withdrawals as well as groundwater extractions is essential to enhance the scope and integrity of the Cap mechanism and bring diversions within the sustainable yield limits. This study lays ground for a detailed volume assessment calibration of each OFS within a water basin, within the prospect of using such information to enable a multi-source remote sensing monitoring system.

1. Introduction

Inland Australian agriculture is faced with unreliable rainfall pattern, as well as excess of poorly productive land because of lack of water. Crop production is often limited by the deficit between crop demand and effective rainfall (Lisson et al., 2003). Australian government is buying back water entitlements from farmers to maintain environmental flows and water for cities and industries. There is an obvious increasing competition for available fresh water on-farm through standard irrigation channels. Recent studies (Qureshi et al., 2010) have noted that until recently in the MDB, farmers could construct small dams (On-Farm water Storage; OFS) to capture the rainfall on their properties and access groundwater at a cheaper price than surface water. They also quote that a CSIRO study estimated total stream flow in the MDB to be around 2200 GL. This resulted in an estimated total stream flow reduction of 1900 GL per year. Similarly, the impact of groundwater pumping across MDB may reduce annual stream flow by some 300 GL (Qureshi et al., 2010). NSW Agriculture (1999) mentions three types of beneficial reasons why a farmer is having on-farm water storage built. The first one is economic. Water can be used more efficiently by capturing and re-using it along with its nutrients. Also, it is a management advantage during peak period of water availability when it is stored as a buffer for drier periods.

The second reason is environmental where farm effluents are kept within the farm boundary, OFS is a buffer of stormwater volume and impact on erosion and it also reduces the demand on dams at peak request period. Finally, they identify an 'engineering' benefit where an excavation on-farm may be planned in such a way as to generate an OFS as a by-product of that excavation itself. Recent thinking in water policy under the Commonwealth government considers extending the Cap (MDBC, 1999) over surface water to OFS as they are not currently covered under the Cap and eluded the effective water policy arrangements across users and the states (Qureshi et al., 2010). A unified approach to Cap implementation involving water diversions from the river system, OFS and other direct diversions and withdrawals as well as groundwater extractions (Crosbie et al., 2010) is essential to enhance the scope and integrity of the Cap mechanism and bring diversions within the sustainable yield limits. Traditional means of assessing an OFS volume are by conducting a bathymetric survey, mostly in OFS of large sizes, due to state dependent licensing requirements (Baillie, 2008). Typically, such survey results in the availability of several cross sections according to the OFS shape. Because of the lack of survey of other than large OFS, underestimation of water diversions in MDB is a chronic state of under-measurement leading to under-management.

ISSN 1686-6576 /

Licensed OFS surveyed were used to classify OFS types and related to remotely sensed open water areas in Baillie (2008). Results from such classification combined with remote sensing already gave large differences with ABS (2006) and Baillie (2008).

2. Background: OFS Monitoring with Remote Sensing

On ground consultants bathymetric surveys have been carried out for a selection of water storages within the farms. Those depth-volume relationships were used to relate to remote sensing estimates of area for water storages as in Baillie (2008) for given dates of common availability of remote sensing and bathymetric data. Having such information permits relationships between areas of observed open water at any high resolution remote sensing image revisiting day. This is enabling the drawing of relationship between bathymetric curves to the area curves. Initial steps involve estimation of open water surface area within the geographical boundary of the On-Farm water storages. Extracted area values are propagated to the area-volume curves from bathymetric survey (not shown for privacy reasons) for each satellite image dates available. This was used to apply remote sensing area for the overpass day OFS volume extraction (Figure 1 and Figure 2). Multi-source remote sensing can increase revisiting frequency, applicable sensors can range from submeter/meter (Ikonos, Quickbird, Worldview etc) to less expensive/free sensors (Aster, Spot, ALOS, IRS, Landsat etc). In this way, calibrated OFS can be monitored from space at any available satellite overpass date in the future. This can enable farm based monitoring of LSD to have increased accuracy in volume and time thus reducing uncertainty of modelling.

Figure 1: Landsat 5 TM images for a sample farm and its OFS area (29-11-2008 and 30-04-2009)

Figure 2: Landsat 5 TM images for another sample farm and its OFS area (20-10-2008 & 15-05-2009)

3. Objectives

This study is proposing a generic framework to benchmark depth-area-volumes for a vast amount of OFS in a given water basin of interest. The main methodology demonstrated here is replacing traditional bathymetric surveys by LIDAR surveys under the condition of fully-automated processing. This methodology is brought into perspective under a hypothetical fully integrated methodological framework (OFS monitoring by remote sensing; OMRS) whereby multi-source remote sensing is used to generate location identification for each unique OFS, diagnoses optimized LIDAR-carrier flight paths and open water detection for monitoring water volumes in LIDAR-benchmarked OFS.

4. Methodology for Depth-Area-Volume Curves from Airborne LIDAR Data

With the arising of LIDAR data from airborne surveys, the time taken by bathymetric surveys can be reduced, but most importantly the number of OFS that can be surveyed in a single day by an airplane is dramatically higher than by bathymetric survey teams. We are presenting here an automatic method to extract depth-area-volume relationship curves from an identified OFS. An initial stage in the methodology is to use one of the many water extraction algorithms (Xiao et al., 2005 and Roy et al., 2005), to identify water bodies in their maximum extents (cumulative temporal extension of boundaries). Figure 3 shows the complete flowchart of the proposed methodology. Once identified and singled out by clumping (r.clump; Neteler and Mitasova, 2007) a LIDAR survey can be defined, through an optimization algorithm (v.net.*; Neteler and Mitasova, 2007) to cover the areas where water storages (human or natural) were identified. If need be at this point, create a morphology moment algorithm to separate the man-made from the natural ones (man-made are often rectangle/squares). Once this is done, and some human operator check is done on the identified sets, the LIDAR survey can return the elevation information. LIDAR data (.las) was extracted using the LIDAR open-source library (liblas, 2010) within its Debian/Linux default installation. A Bash script was generated to automatically convert the .las original data into point data (.shp) using las2ogr tool. The shapefiles generated were then imported into GRASS/GIS environment (Neteler and Mitasova, 2007) where contiguous tiles were geographically merged together into one dataset using v.patch. Spline interpolation provided by r.fillnulls permitted the production of contiguous raster grid of continuous values (Figure 4). At this point, inspection of the surface through thresholds permits to roughly identify boundary altitude values as shown in Figure 5. Afterwards, a clumping procedure (r.clump) will provide data for area statistics (r.stats) for each clump. Areas between 100-200 Ha are extracted as OFS units. Each unit is then separately processed through open-close operators on the boundaries to refine the highest common altitude throughout the water storage boundary (the effective water containment highest boundary). Once identified, a vector (r.to.vect) boundary is issued. This boundary vector is then used to clip the spline raster surface initially created. It is now possible to geographically extract z-axis slices of the OFS to compute areas, then volumes with depth (Figure 6). Minimum and maximum elevations are extracted with r.info. A 10 cm z-axis step is arbitrarily chosen as z-dimension resolution for extraction of area through pixel count with a known pixel size (through r.info) converted into pixel area. An iteration system will calculate area for each z-slice from the bottom z-axis boundary available within that OFS. It will then extract (through r.univar), the volume in m^3 which is then converted in to ML on the fly. Finally, the depth is extracted from the difference between the bottom boundary and the z-slice altitude. All three dimensions data are then exported in an output text file. On a side note, each slice is exported to a .gif picture file for integration into an animation using gifsicle (gifsicle, 2010), for a final operator check.

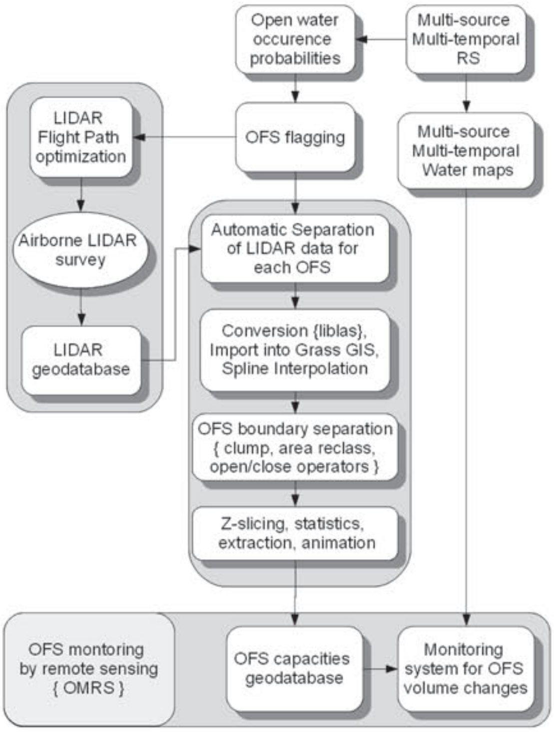

Figure 3: Flow chart of the proposed methodology

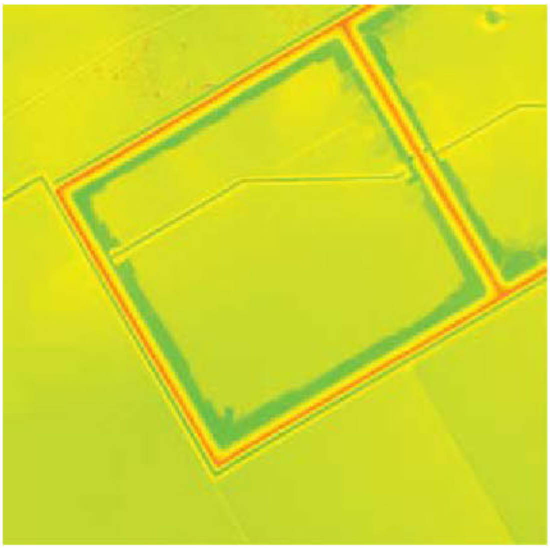

Figure 4: Spline surface of water storage from LIDAR data

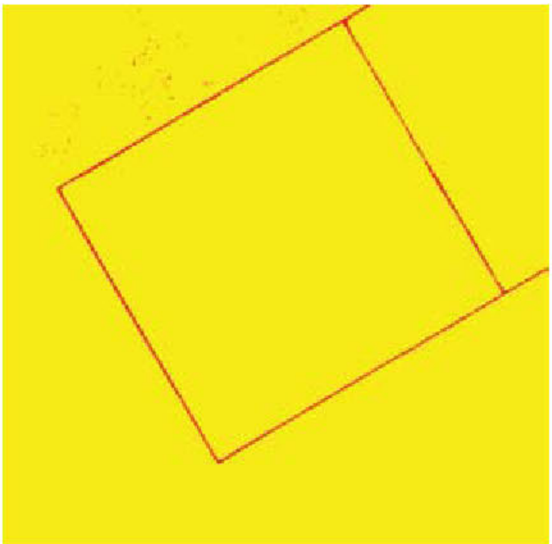

Figure 5: Water storage boundary

Figure 6: Water storage extracted from spline surface with the boundary vector

5. Results

Derived information from z-axis slices of OFS elevation data is now available as depth/volume/area data streams that can be extracted into one to one relationships (Depth-to-Volume in Figure 7 and Area-to-Volume in Figure 8). The Depth-to-Volume relationship shows acceptable accuracy at small volumes, though it is more accurate at larger volumes (Figure 7). On the other hand the Area-to-Volume relationship in Figure 8 is showing a good sensitivity of area input to volume estimation output until an inflection point at 125 hectares, where any small change in area input provides a large change in volume estimation. If the OFS is reaching such high volume storage condition, care should be taken to have proportionally higher spatial resolution imagery (~5m or less) for water area estimation, so as to compensate the sensitivity of the estimation through the relationship in Figure 7.

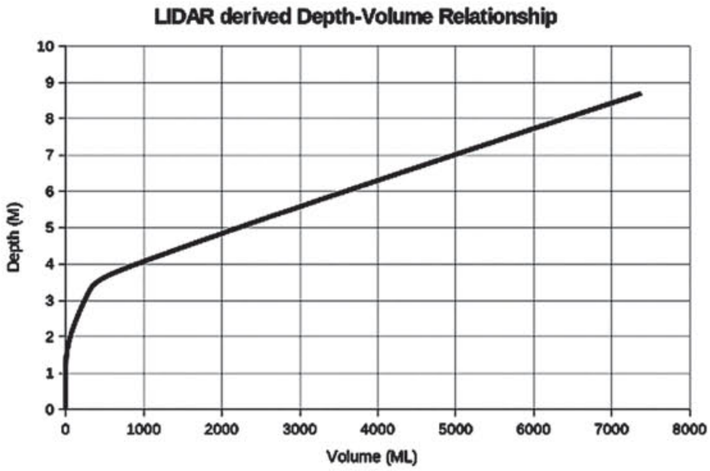

Figure 7: LIDAR based water storage Depth-Volume relationship

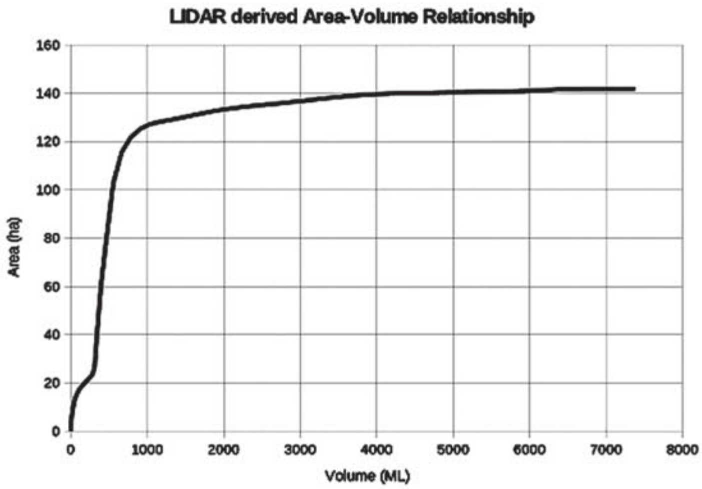

Figure 8: LIDAR based water storage Area-Volume relationship

Monitoring of OFS from remote sensing can be computed using the unique relationship developed for each OFS by this method. The generation of the GIS-bound library of Area-Depth-Volume relationships for all OFS of the watershed studied permits a comprehensive monitoring of water storage volumes at all available satellites revisiting times.

6. Conclusions

Some accuracy measurements issues are obviously linked to the slope of the OFS earthen walls, which tends towards a vertical as elevation increases on the sides of the OFS. Measurements of water areas from satellite remote sensing become less accurate as the wall tend to vertical. The technique itself is also dependent on the limitations of visible/near infrared remote sensing in general, which Lidar belongs to, and which the satellites used for open water area monitoring also belong to. Namely, they have interaction with vegetation and clouds, as both reflect those electro-magnetic spectrum ranges. Demonstration has been made that an automatic extraction of LIDAR based depth-area-volume relationship for on-farm water storages can be implemented from free and open source GIS software. Combined with an automatic identification of location of OFS (further study), this will permit the generation of a geodatabase of OFS storage capacities, by integrating airborne LIDAR optimized flights to the OFS locations and chain process those unique information for each OFS. Finally, as shown in the first part of this paper, the use of multi-source remote sensing enables the monitoring of open water in each of the OFS. This methodology is enabling the real-time monitoring of the volume of stored water in all LIDAR-benchmarked OFS. Future directions of research should look into the means of developing a fully automatic processing system based on the methodology described in this research. Also, a similar experiment should be made where a precise bathymetric survey was very recently carried out in order to assess the algorithm modifications needed to converge the quantities found through this method to the survey ones. Finally, natural OFS types are far more complex to identify, analyze and monitor as Lidar interacts with vegetation canopy. Further studies are needed to address their identification, quantification of area-depth-volume and monitoring volumes changes.

Acknowledgements

The authors would like to acknowledge The NSW office of water for providing the LIDAR data.

References

Australian Bureau of Statistics, 2006, Water Account Australia 2004-05, ABS, Catalogue No. 4610.0.

Baillie, C., 2008, Assessment of Evaporation Losses and Evaporation Mitigation Technologies for On Farm Water Storages across Australia, Irrigation Matters Series, No. 05/08, CRC-IF.

Crosbie R. S., McCallum J.L., Walker G.R. and Chiew F.H.S., 2010. Modelling the Climate Change Impact on Groundwater Recharge in the Murray-Darling Basin. *Hydrogeology Journal*.

gifsicle, 2010, Internet retrieval from www.lcdf.org/gifsicle/

liblas, 2010, Internet retrieval from liblas.org.

Lisson, S. N., Brennan L. E., Bristow, K. L., Keating, B. A. and Hughes, D. A., 2003, DAM EA$Y--Software for Assessing the Costs and Benefits of On-Farm Water Storage Based Production Systems. Agricultural Systems. 76(1):19-38.

MDBC, 1999, Murray-Darling Basin Cap on Diversions. Water Year 1997/1998. Striking the balance. Cap Archives at mdbc.gov.au

Neteler, M., and Mitasova H., 2007, Open Source GIS: A GRASS GIS Approach. Third edition. 420 pages, Springer, New York.

NSW Agriculture, 1999,. On-Farm Water Storages. Guidelines for Siting, Design, Construction And Management.

Qureshi, M. E., Grafton, R. Q., Kirby, M., and Hanjra, M. A., 2010, Understanding Irrigation Water use Efficiency at Different Scales for Better Policy Reform: A Case Study of the Murray–Darling Basin, Australia. Water Policy doi:10.2166/wp.010.063.

Roy, D. P., Jin, Y., Lewis, P. E., and Justice, C. O., 2005, Prototyping a Global Algorithm for Systematic Fire-Affected Area Mapping using MODIS Time Series Data. *Remote Sensing of Environment*. 7(2):137-162.

Xiao, X., Boles, S., Liu, J., Zhuang, D., Frolking, S., Li, C., Salas, W., and Moore, III B., 2005, Mapping paddy rice agriculture in southern China using multi-temporal MODIS images. *Remote Sensing of Environment*. 95(4):480-492.