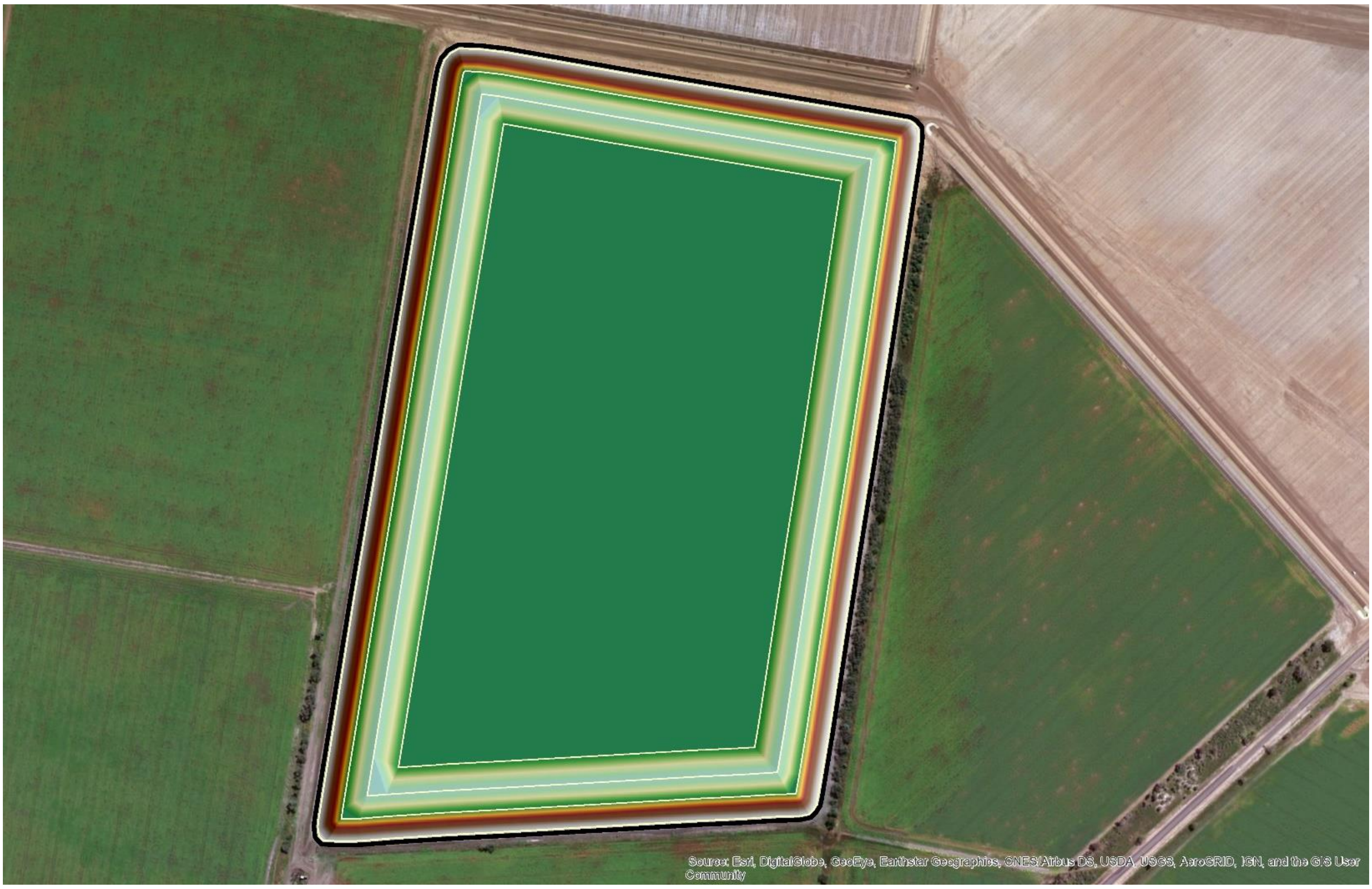

Storage Bathymetry Model Update and Application (Gwydir Valley)

Report

Prepared For

Department of Industry: Lands and Water

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1 Introduction

1.1 Project Background

The NSW Healthy Floodplains Project (2017) is an Australian and NSW Government-funded project that aims to reform water management on northern basin floodplains, protecting the environment and the reliability of water supply for downstream water users within the study area. This will be achieved by implementing the NSW Floodplain Harvesting Policy (2013) which will license water extractions from the designated floodplains. Under this policy, the relevant landholders will be required to report the amount of water that is extracted and held in their On Farm Storages (OFS). A key component of calculating the amount of water extracted is to understand the relationship between the easily measured storage water level, and the corresponding volume. This relationship is typically referred to as a “storage curve” or “stage volume curve”

It is estimated that over 1,000 OFS will need to be surveyed. Given the magnitude of this project, traditional land survey would not be cost-efficient (Hamstead estimated the costs to range from $1,500 to $3,000 per OFS). Instead, the method developed by the Office of Environment and Heritage (OEH), known as the Storage Bathymetry Model (SBM) will be used to generate stage volume curves for each of the OFS. The SBM method utilises LiDAR derived digital elevation models (DEM) as opposed to ground survey.

Although this method is an order of magnitude cheaper and quicker than ground survey, there are a number of challenges that need to be overcome. The main challenge is the inability of LiDAR to penetrate water. The LiDAR laser, when it hits water, is scattered rather than penetrating the water and reflecting at the ground surface, therefore the resulting DEM represents the water surface rather than the true ground surface.

This was resolved by the OEH Healthy Floodplains team (in conjunction with DHI Group) who developed the SBM to estimate bathymetry beneath the standing water. The model was applied to five storages with known stage-volume curves and was found to be highly accurate. A further 50 storages were then analysed to refine the extraction method. Figure 1 below, illustrates the issue with using LiDAR.

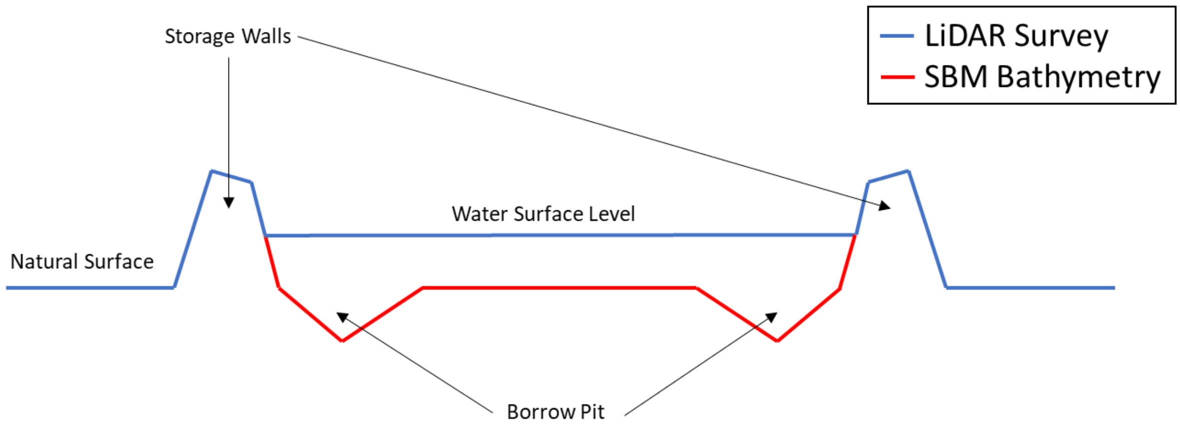


Figure 1 Conceptual representation of an OFS and the SBM bathymetry

1.2 Project Objectives

The objective of this study was to provide Department of Primary Industry - Lands and Water (DPI - Lands and Water) with a reliable stage volume curve for all OFS within the Gwydir Valley.

To ensure quality, the method had to be defendable, and reproduceable. This report outlines the methodology undertaken to develop the HydroSpatial stage volume curves.

Note that this method has now been applied to the other valleys within the Healthy Floodplains Project (Macquarie, Namoi, Border Rivers and Barwon Darling).

1.3 Data Available

The data made available by the DPI - Lands and Water for this study included:

- LiDAR derived Digital Elevation Model at a 1 m resolution, captured between 2008 and 2014
- Outlines of the storages that required a stage volume curve
- The original pilot study
- Surveyed storage curves selected storages collected as part of the Healthy Floodplains Project
- Farmer self-reported storage characteristics derived from DPI - Land and Water's Irrigator Behaviour Questionnaire (IBQ)

In addition to these data, the following additional data was utilised as part of the project:

- High resolution (0.5 m) aerial photography captured by the NSW Land and Property Information, available through their public web map service.
- Photogrammetry derived 5 m resolution DEM developed by the NSW Land and Property Information, available through the Geoscience Australia's "ELVIS" website. Referred to as the ADS DEM.

A number of storages were located beyond the extent of the LiDAR capture area, these storages were therefore calculated using the ADS DEM. This is discussed further in Section 5.2.2.

2 Storage Classification

A total of 414 storage outlines were supplied by DPI – Lands and Water for the Gwydir Valley. This included a number of storages that were not applicable for this study. Therefore, the initial step in the project was to classify the storages based on how they would be treated as part of the SBM. This classes used are outlined in Table 1.

Table 1 Summary of Gwydir Storage Classification

Class	Number of Storages	Treatment
Standard OFS	310	Calculated
Surge/Temporary Storage	82	Not Calculated
OFS outside of LiDAR (excluding surge storages)	19	Calculated using ADS DEM where applicable
Special Cases	3	Individually treated

3 Storage Bathymetry Model

3.1 Storage Bathymetry Model Derivation

The SBM is essentially an empirical model based on the geometric relationships between different aspects of the storage. One of the key theoretical assumptions of the SBM is that the OFS are built in a similar way, particularly that:

- The height of the wall corresponds to the width of the wall (i.e. wall batters are similar)
- The volume of the wall corresponds to the volume of the borrow pit (i.e. the material used to build the wall is drawn from the borrow pit within the storage)

Given these two assumptions, relationships between the height of the wall and the wall width and borrow pit geometry can be determined based on analysis of storages that were empty during the time of LiDAR capture. The revised SBM was developed by analysing 68 OFS. These storages varied in shape, volume and surface area and were found across the Gwydir and Namoi floodplains.

Figure 2 shows a typical simplified cross-section of a storage wall and borrow pit, where T equals the top of bank, A is the inside inflection point at the top of bank, B is the inside toe of the bank, C is the bottom of the borrow pit and D is the inside edge of the borrow pit.

The SBM essentially uses the wall height (vertical distance between T and B) to estimate the co-ordinates of all other points, for example the horizontal and vertical distance from T to A. These relationships are then used to generate the bathymetry of the storage underneath the water level.

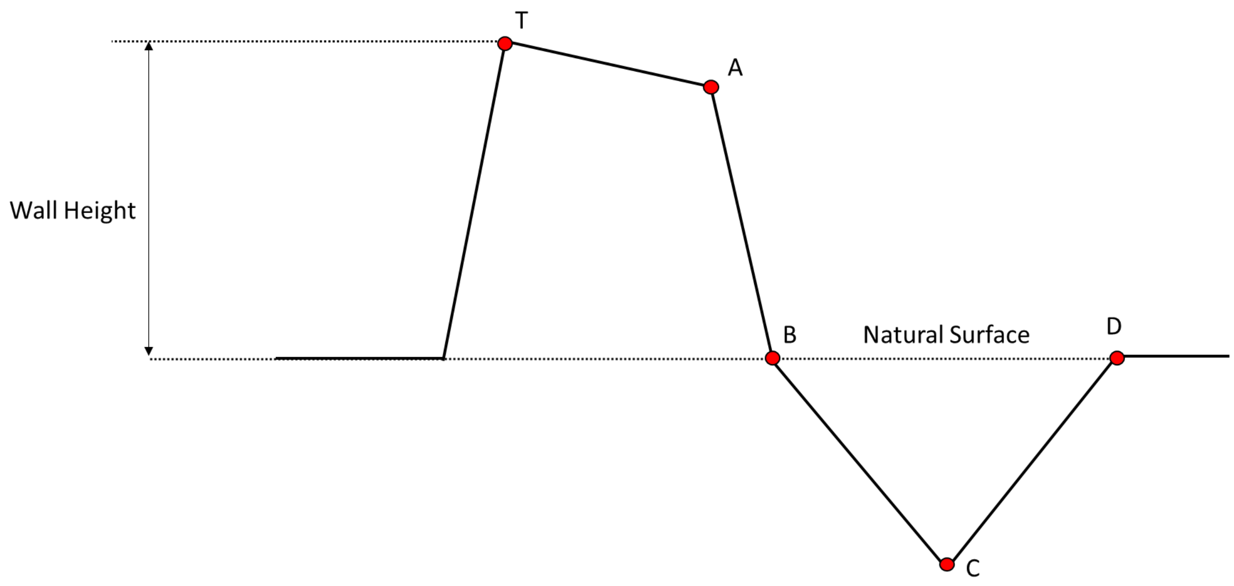


Figure 2 Cross Section of a Typical Storage

One of the limitations of the initial SBM was uncertainty over the applicability of the SBM for storages that were smaller or larger than those sampled. The initial SBM utilised only five empty storages and had a uniform set of relationships for all storages regardless of size. The revised SBM therefore separated out storages based on their size and unique parameters were developed for each size category. The sizes used were:

- Extra small storages (estimated to be below 200 ML capacity)
- Small storages (estimated between 200 and 1,000 ML capacity)
- Medium storages (estimated between 1,000 and 3,000 ML capacity)
- Large storages (estimated to have over 3,000 ML capacity)

Note that for very large storages the SBM may over-estimate the depth of the borrow pit. For example, rather than dig a deeper borrow pit to construct a higher wall, the borrow area may increase to limit the risk of running into seams of sand and to reduce cost. While this would affect the shape of the bottom of the curve, the net effect of this on the overall storage volume would be negligible.

3.2 Full Supply Level Assumptions

One of the key outputs of the SBM process is the estimation of the full supply volume (FSV) of the storage. The FSV is found by taking the average of the TOB level and Point A level and then deducting a nominated freeboard. This freeboard is used for the OFS safety (i.e. to prevent wave action overtopping and eroding the wall) and is typically around 0.5 - 1 m.

The full supply level relies on two key assumptions:

- The amount of freeboard.
- The Top of Bank (TOB) reference point for freeboard.

Freeboard has been assumed to be 1 m for all storages.

For the TOB reference point, we have used the average TOB level that was calculated as part of the SBM process. However, in many cases the TOB level varies by up to around 0.3 m and it is unknown exactly where the freeboard is measured from.

Anecdotal evidence is that the freeboard can be measured from the outside lip of the bank (usually the highest point) or alternatively from the mid-point of the road running around the storage bank. Typically there is around a 0.2 – 0.3 m fall across the road so potentially the TOB reference point could vary by up to around 0.6 m.

Given the uncertainty around the TOB, freeboard and therefore the full supply level, the SBM has been setup so that the assumptions can be easily changed either for all storages, or individually if better information becomes available.

3.3 Application of the SBM

The SBM is an excel based tool, however application of the SBM to develop a stage volume curve is primarily through GIS processing. The key steps to applying the SBM are:

1. Derivation of the OFS outline
2. Estimate the Top of Bank (TOB) and Natural Surface (NS)
3. Run the SBM
4. Convert the SBM co-ordinates into contour lines
5. Generate a Triangular Irregular Network (TIN) from the contour lines
6. Convert the TIN to a Raster
7. Generate a stage volume table
8. Generate an OFS report

Each of these processes is outlined in further detail below. Many of these processes can be partially automated by using the programming language VBA to develop a “Macro” as well as the ArcGIS Model Builder or partially automated using the ArcGIS Batch Processing tools.

This automation allows for easy update to the storage curve if the OFS is modified, or if the assumptions underlying the SBM need to be revised.

3.3.1 Derivation of OFS Outlines

The outlines produced by previously were modified to better represent the storage Top of Bank (TOB). The DEM was used determine the locations along the levee with the highest elevations (relative to the storage). The outlines for each storage were fixed manually.

The outline is likely to fall within 2 m of the true TOB level and this error is relatively insignificant given the size of the storages. An example storage outline against the DEM is shown in Figure 3.

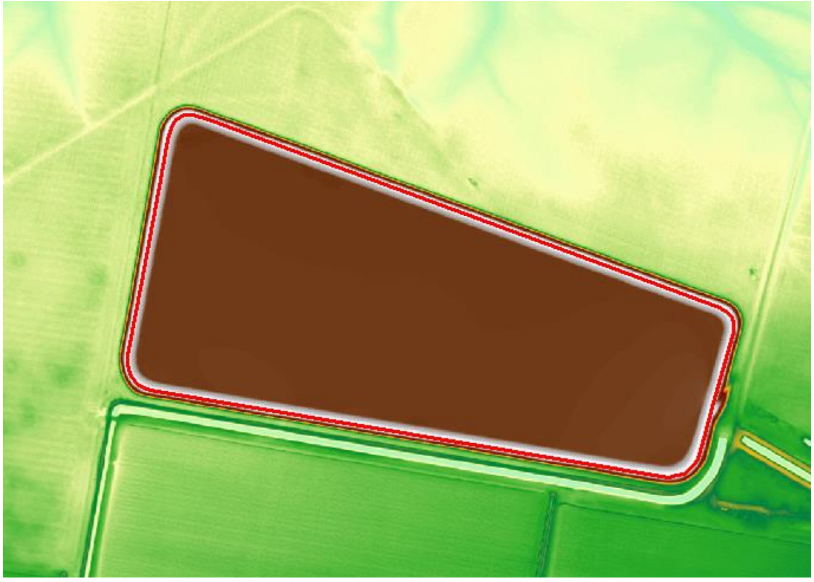


Figure 3 Example storage outline (red line) when compared to the DEM (background colours)

3.3.2 Estimate Top of Bank and Natural Surface

Five cross-sections were taken from different sides of each of the OFS. For each of the sections, the TOB and Natural Surface (NS) values were extracted. These values were then averaged to give a mean TOB value and a mean NS value.

In many of the sections, there was some variability in the natural surface outside of the storages, therefore a representative value based on a visual assessment of the section.

3.3.3 Storage Bathymetry Model

Prior to the TOB and NS values being input into the SBM, the storages were separated based on their size. The size was estimated by taking the depth (TOB minus NS) and multiplying this by the area to provide an approximate size of the storage. Each storage was then run through the appropriate version of the SBM (extra small, small, medium and large).

The SBM then produces a value of the horizontal and vertical offset from the TOB outline for each of the set points shown in Figure 1. The vertical offset is then reduced to AHD (Australian Height Datum) by subtracting the offset from the TOB elevation.

3.3.4 Generate Contours representing the SBM outputs

Once the offsets for the modified bathymetry have been generated by the SBM, these need to be converted into a format that can be interpreted by GIS packages. This is done by generating buffers of the storage outlines where the buffer distance is the horizontal offset from the TOB and an attribute is created for each line to include the elevation. These lines are effectively contours within the storage.

Note a negative distance is used in the buffer tool to generate internal buffers. Figure 4 shows an example of the output buffers, where the black lines are the contours of the SBM.

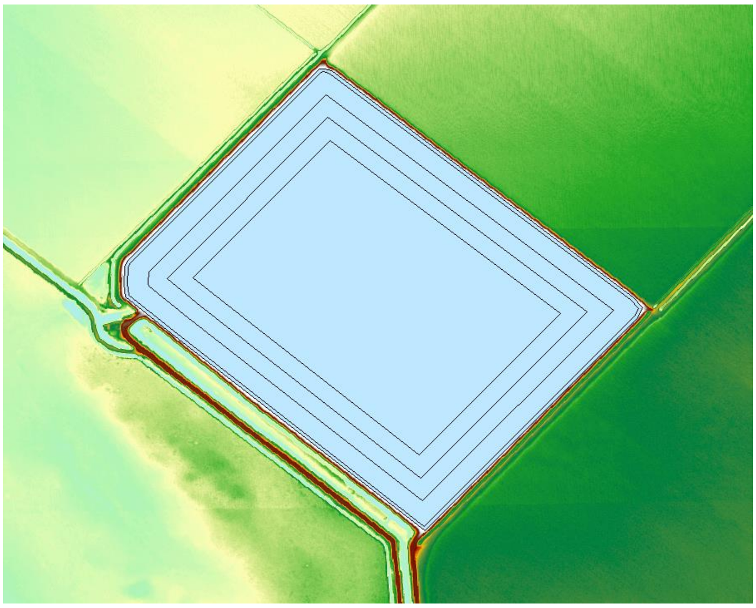


Figure 4 Example Buffer Output

3.3.5 Generate a TIN from the Contours

The contours are then used to generate a TIN file. A TIN is a linear interpolation between the contours and it was found that the TIN process was the only way to exactly re-produce the SBM results in a three-dimensional model. Other interpolation methods, such as inverse distance weighting, kriging, splining etc tended to produce results that varied from the SBM when comparing storage cross-sections.

3.3.6 Convert the TIN to a Raster

The TIN is then converted to a raster format with a 1 m grid resolution. This step was necessary as the tool that converted the three-dimensional model could not directly read TIN files.

3.3.7 Generate the Stage Storage Table

A GIS tool is then used to generate the stage volume relationship. The output of this tool is a table of elevation values and the corresponding volume. The tool typically produces values at 10 different elevations, including the highest and lowest elevations and the other values at equal intervals between.

3.3.8 Create an Individual Storage Report

The Stage Storage Table is then copied into an excel based report template and saved as a new file. Further detail of the report template is outlined in Section 4.

3.3.9 Automation Summary

A number of the SBM processes have been automated to some extent using Excel based Macros and GIS based python scripts. The automated processes are outlined in Table 2. This allows for many aspects of the SBM outputs to be relatively simple to change. The following could be easily changed within the outputs if new information were to become available:

- Change to TOB level (for freeboard estimate)
- Changes to output report formatting
- Changes to freeboard assumptions (e.g. from 1 m to 0.5 m)

Table 2 Summary of Automated Processes

Process	Automation
Derivation of the OFS outline	Manual
Estimate the Top of Bank (TOB) and Natural Surface (NS)	Manual
Run the SBM	Automated (Macro)
Convert the SBM co-ordinates into contour lines	Manual
Generate a Triangular Irregular Network (TIN) from the contour lines	Automated (Python)
Convert the TIN to a Raster	Automated (Python)
Generate a stage volume table	Automated (Python)
Create an Individual Storage Report	Automated (Macro)

4 Stage Volume Curve Reports

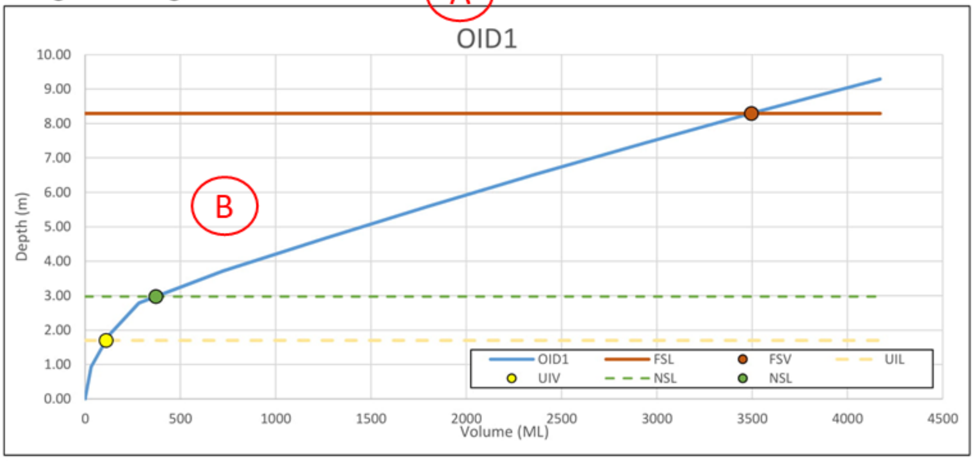
The final output for each storage is a one page excel based report showing the storage information, the curve and outputs. Figure 5 shows an example storage report, some of the key features of the storage report are highlighted by letters and explained in Table 3. It is important to note that all volume figures have been reported to the nearest 10 ML as this is likely the level of precision obtained by the SBM process.

Table 3 Storage Report Key Features

Feature	Description	Comments
A	Storage Title used by HydroSpatial	The OID number is a unique number for each storage and relates to the storage outlines shapefile
B	The Storage Curve	The curve includes markers showing the Full Supply Volume, the Natural Surface and a User Input Level
C	Property Information	This property information has been derived from data supplied by DPI - Lands and Water
D	Storage Parameters	These are the key storage parameters used in the SBM, particularly the natural surface and top of bank elevations
E	Stage Volume Variables	These are some of the key features of the storage, FSL is the full supply level, FSV is the full supply volume, Freeboard Reference is the point at which the freeboard is deducted from to obtain the FSL and the freeboard is the freeboard assumed. UIL is a user input level that can be modified to determine the storage volume at any height (useful for monitoring)
F	The Storage Relationship	This is the output of the SBM process, the relationship between height (expressed as Depth) and volume
G	Abbreviations	Definitions for abbreviations used within the storage report

Stage Storage Curve for OID1

A



Storage Information

C

OID Number	OID1
EOI Number	GXXXX
Name on Application	Owner
Property Name	Property
Actitivy Number (OFS)	From IBQ
OFS Reference	From IBQ
OFS Classification	From IBQ
OFS Purpose	From IBQ

Storage Parameters

D

TOB (m AHD)	201.682
NSL (m AHD)	195.36

Stage-Storage Curve Variables

E

FSL (m AHD)	200.68
FSV (ML)	3500
FB Reference (m AHD)	201.682
FB (m)	1.00
UIL (m AHD)	1.70
UIV (ML)	110

Stage Storage Table

F

Depth (m)	Volume (ML)
0.00	0
0.93	31
1.86	126
2.79	280
3.72	720
4.65	1250
5.58	1790
6.50	2350
7.43	2940
8.36	3540
9.29	4170

List of Abbreviations

G

EOI	Expression of Interest
FB	Freeboard
FSL	Full Supply Level
FSV	Full Supply Volume
NSL	Natural Surface Level
OFS	On-Farm Storage
SBM	Storage Bathymetry Model
TOB	Top of Bank
UIL	User Input Level
UIV	User Input Volume

Figure 5 Example Storage Report

5 SBM Validation

5.1 Comparison to Surveyed OFS

Survey data was made available by DPI - Lands and Water. This was extracted from the IBQ datasets for each of the properties. In some instances, it was impossible to relate the IBQ storage data to a storage within the shapefile provided by DPI - Lands and Water. Overall, 42 storages were located and survey data was compared to the SBM outputs.

All 42 of the survey datasets were only surveyed to a local datum, and not reduced to AHD. This makes direct comparison with the SBM data difficult. The survey and SBM datasets were initially aligned by assuming that the survey and SBM used the same TOB. A summary of the results at full supply level for these unadjusted comparisons are shown in Table 4.

Review of the comparisons where the FSV difference was greater than 10% showed that it was likely that in most cases, the only issue was the TOB level. Examination of a number of TOB profiles showed that it is reasonably that the TOB value used in SBM and the survey TOB could be up to around 0.5 m different, depending upon where in the storage the TOB is estimate.

The TOB was then varied in either the SBM or Survey data (whichever was larger) to attempt to match the curves together, conservatively, the TOB was only altered by a maximum of 0.3 m. Additionally, a number of storages were identified as having significant issues that indicate either an error in the survey or a mismatch between the SBM ID and the survey ID. These storages (OID11, 18, 94, 335, 344) were removed from the comparison.

The updated results are shown in Table 5. These values are likely to be a fairer comparison as the datum shifting issue described above is partially accounted for and potentially problematic survey data has been removed. It is important to note that some of the storages compared were very small (OID 17 and 33), and therefore a small difference in the absolute volumes leads to a large percentage difference.

Overall the accuracy of the SBM process, taken from Table 5 and simplified, is estimated at around 5% at the full supply volume. At the lower end of the curve the accuracy would be decreased, particularly within the borrow pit. However as the lower end of the storage curve has a much lower volume, this is not likely to be an issue in applying the results.

Table 4 Comparison of Undadjusted TOB results at the full supply level

Comparison	Difference (survey vs. SBM)
Full Supply Volume (%)	8.29
Full Supply Volume Standard Deviation (%)	11.85
Full Supply Volume (Ml)	160

Table 5 Comparison of adjusted TOB results at full supply level

Comparison	Difference (survey vs. SBM)
Full Supply Volume (%)	4.13
Full Supply Volume Standard Deviation (%)	3.84
Full Supply Volume (Ml)	100

The results given in Table 4 and Table 5 use the average of the absolute difference between the survey and storage data i.e. there are no negatives. When the average difference is calculated when the negative values are included, the results are on average within 1%. This suggests that the SBM does not consistently over or under-predict the storage volumes and suggests that there is no systematic error in the processes that could be improved.

The relative accuracy, i.e. the difference in volume between two levels, is also likely to be considerably higher than the 5% absolute accuracy. This change in volume is what is being measured as part of floodplain harvesting and therefore is more important than the absolute accuracy.

5.2 Consistency Checks

5.2.1 Full Supply Volume vs. Area x Depth

Another simple check undertaken to ensure that the SBM results are consistent was to compare the FSV from SBM to a simple estimate of volume using GIS. The GIS volume was calculated by multiplying the TOB area by the depth (difference between TOB and NS minus 1 m freeboard).

Figure 6 shows the results of the comparison. When a linear regression is undertaken on the results (with an intercept set to 0) there is a very strong relationship (r2 - 0.97) and the relationship is effectively 1 to 1 (y = 0.99x).

This “sanity check” suggests that the SBM process is both consistent and robust.

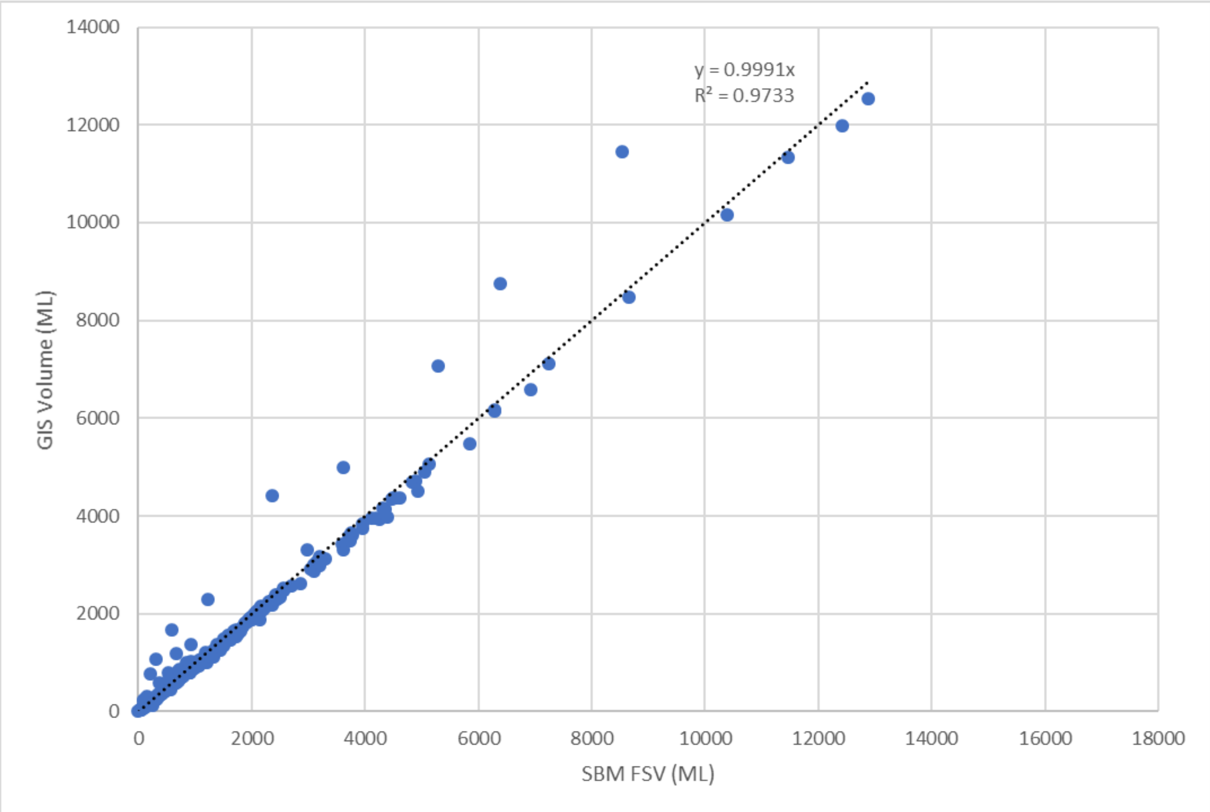


Figure 6 Comparison of SBM FSV and GIS Volume

5.2.2 Comparison of ADS and LiDAR Results

To compare the results obtained by the ADS DEM, four storages were selected where there was an overlap between the LiDAR and ADS DEM. The selected storages (OID77, 96, 144, and 360) were drawn from the comparison between the survey and SBM results and selection was based on the consistency between the results of the two datasets. This provides confidence that the SBM and Survey data are both accurate.

Figure 7 shows an example profile extracted for estimating the TOB and NS using both the LiDAR and ADS datasets. The figure shows that there is likely to be some differences in the TOB and NS estimation. This is to be expected as the 5 m resolution ADS would be smearing out the lip of the bank by averaging it across a 5 m distance. A slight shift in the TOB location is also observed, which may impact the digitisation of the outline.

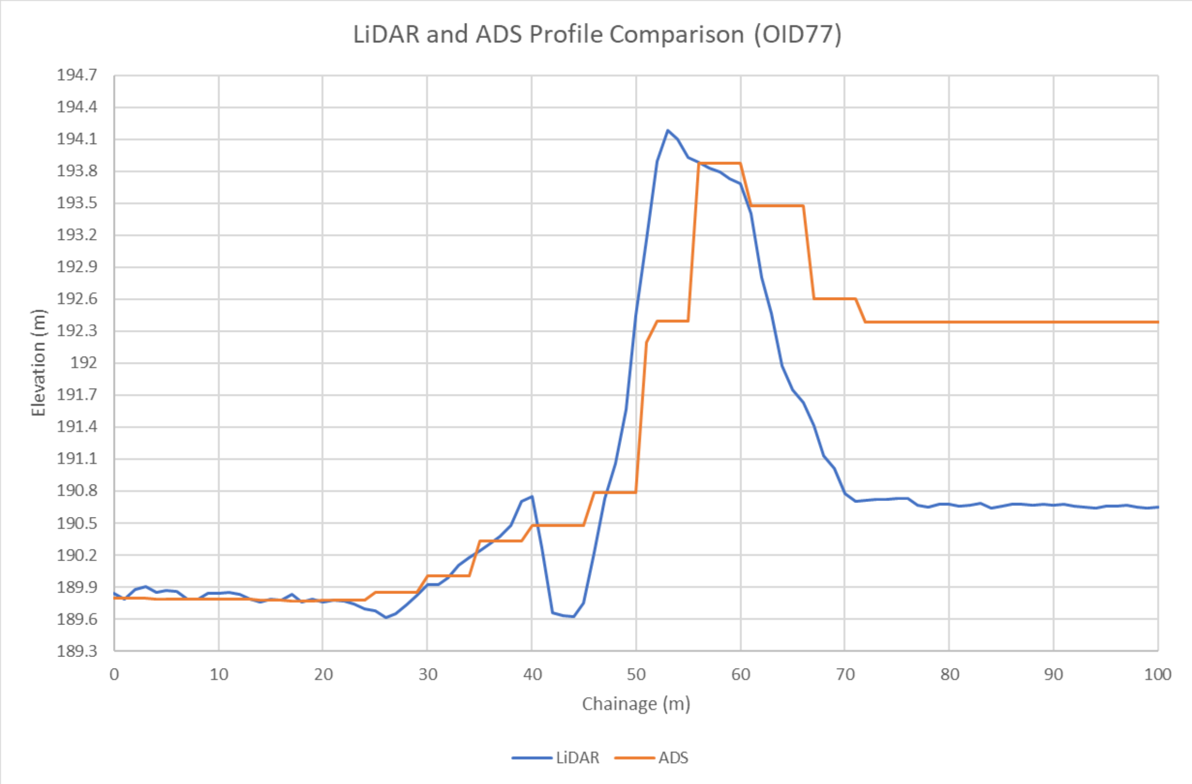


Figure 7 LiDAR and ADS Comparison

The results of the ADS and LiDAR comparison are shown in Table 6. There is a significant difference for the smaller storages, with a larger difference in height and subsequent larger differences in volumes. For the larger storages (OID144 and OID360) the comparison is better, with a difference of under 10% at TOB volume and FSV.

It was expected that for smaller storages the percentage difference would be greater, however it is unknown why the smaller storages performed worse in an absolute sense.

Given the large uncertainty around the accuracy of the ADS storages, it is recommended that where available, additional LiDAR, high quality photogrammetry or ground survey is undertaken rather than rely on the ADS data.

Table 6 ADS LiDAR Comparison

	LiDAR	ADS	Difference
Height (m)			
OID77	4.67	3.38	1.30
OID96	5.55	4.10	1.45
OID144	5.41	4.99	0.41
OID360	5.26	4.94	0.32
TOB Volume (ML)			
OID77	900	670	229
OID96	724	532	192
OID144	2132	1984	148
OID360	1683	1602	82
FSV (ML)			
OID77	702	471	231
OID96	589	399	190
OID144	1732	1582	149
OID360	1358	1273	84

5.3 Practical Considerations for applying the results

The SBM results are presented as both depths above the bottom of the borrow pit (gauge zero) as well as in reduced levels (to AHD). It is our understanding that most OFS simply have gauge boards that have not been reduced to AHD and therefore when reporting floodplain harvesting, farmers will be providing changes in the depths.

This is potentially problematic as the variation in the depth of the borrow pit in OFS is highly variable, therefore there is likely to be considerable differences between the gauge zero in the SBM derived curves and the local gauge boards.

While the TOB level has some uncertainty (as discussed in Section 3.2) it is likely to be significantly less than the gauge zero level and for this reason it is recommended that the air space above the water level is used to measure the freeboard rather than the depth within the storage. This is shown graphically in Figure 8 where it is recommended that distance X is estimated to link the gauge level to the SBM derived curve rather than distance Y.

If the gauge levels are reduced to AHD then this would significantly improve the accuracy associated with the comparison between the two datasets.

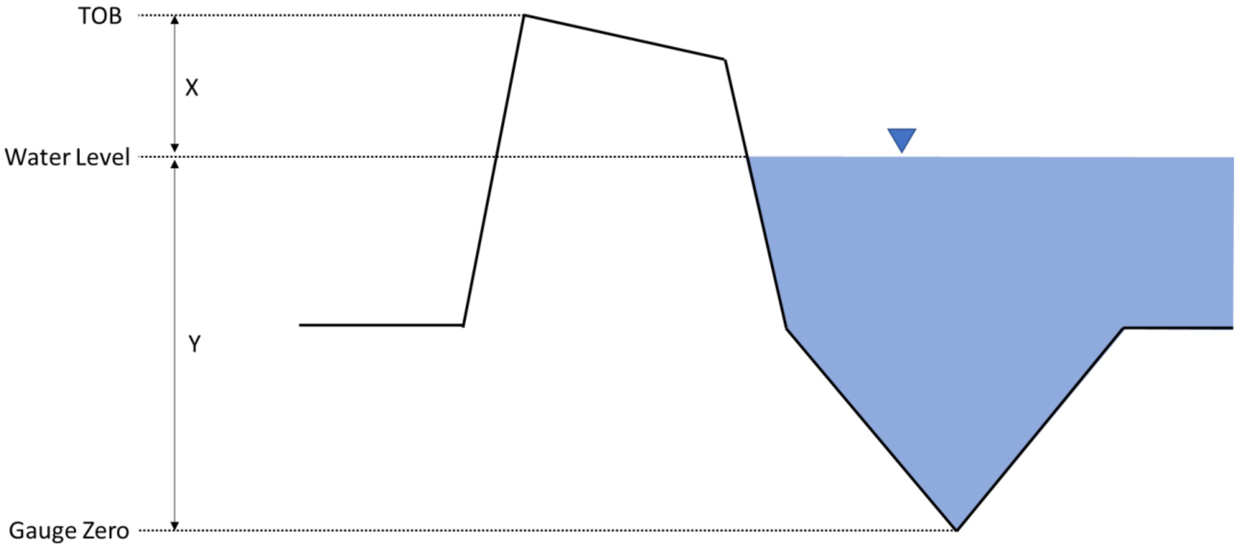


Figure 8 Conceptual Storage Depth vs Air Space measurement

6 Conclusions and Recommendations

6.1 Conclusions

As part of this project, we have revised the SBM and the method in which it is used to generate Stage Volume curves. We have then applied the revised SBM to 332 number of storages within the Gwydir Valley.

Based on the comparison to the surveyed data, we estimate that the resulting OFS stage volume curves are within around 5% of the true volume at both the full supply volume and the total volume. Given that there is no systematic under or over-prediction when compared to surveyed storages, there is no bias in the results and therefore the 5% difference can be taken to be the accuracy level.

This accuracy assessment is the absolute accuracy when compared to a surveyed storage, whereas the intended use of the stage volume curve is to compare the volume at two points in time, such as before and after a floodplain harvesting event. The relative accuracy along the curve (i.e. the change in volume with elevation) is likely to be considerably higher than the absolute error and therefore these volume change estimates are likely to be far more accurate than to within the report 5%.

The ADS storage comparison showed generally acceptable results for two of the four storages examined, however for the smaller storages the errors are significant and therefore the ADS data should not be relied upon.

One of the difficulties with applying the results of this study is the comparison to the OFS gauge, which is unlikely to be reduced to AHD. The estimate of the borrow pit depth is likely to be relatively inaccurate, therefore the comparison needs to be made from the TOB rather than from the gauge zero. As discussed in Section 5.3, the TOB measurement will even have some accuracy issues.

6.2 Recommendations

Given the relatively high accuracy of the results, DPI – Lands and Water can be confident in applying the storage curves for monitoring floodplain harvesting. Therefore, the methodology should continued to be applied to the other valleys within the Healthy Floodplains project.

For storages where there is no LiDAR, the ADS data is not reliable enough to be used as a substitute, therefore it is recommended that additional LiDAR, high quality photogrammetry or ground survey is undertaken for these storages.

While it is not necessary, the accuracy of the measured volumes would be improved if the local gauges were reduced to AHD, this would allow for a direct comparison between the SBM derived stage volume curve and the local gauge.