Australian Government

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Wetland Mapping and Classification Methodology

Overall Framework

A Method to Provide Baseline Mapping and Classification for Wetlands in Queensland

VERSION 1.2

Attachment 4

Mapping Water Bodies Using Density Slicing

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1. Introduction

The mapping technique is based on more than twelve months of product development (Knight 2004a, 2004b). The density sliced water body method has been applied to map open water features across Queensland, including coastal, range and inland steppe environments. The method uses the key water signature defined by Landsat Thematic Mapper (TM) Band 5 along with closely affiliated shadow and greenness signatures in Bands 3, 4 and 5, to map water bodies at a scale of 1:100,000 with a minimum mapping unit of 0.25ha.

The water body mapping method was designed to use the spectrally and spatially corrected (25m pixel) Department of Natural Resources and Mines (DNR&M) State Land and Tree Survey (SLATS) TM imagery, provided through the Queensland Herbarium in 1:250,000 map sheets, although amendments to use whole scenes have been made. The images were captured in 1991, 1995, 1997, 1999 and 2001, with additional images provided for 2000, although these are only used if the 1999 or 2001 imagery is not available or acceptable for application.

Most of the SLATS images are captured during dry and clear-sky conditions, as required for vegetation mapping, and so do not provide a true representation of the maximum wetted extent of actual wetland features. However, benefits are obtained from dry period mapping, including a clearer representation of the internal boundaries of wetlands, the identification of more persistent water features, and a reduction of cloud shadow effects. The use of multi-temporal image sequences increases the likelihood that occurrences of infrequently inundated wetlands are identified and combined into a valid water body feature. Multi-temporal imagery also provides the power to identify landscape changes, such as the introduction of impoundments and ring tanks, and provides a capacity to monitor changes in inundation frequency. The method has incorporated six-band wet scenes with minor alterations.

2. The Method

The signatures used to map water bodies have been found to be the most statistically important in the available three-band (TM Bands 3, 4 and 5) multi-temporal data space, for the development of accurate themes of water body frequency of occurrence through time and across different landscapes. Erdas Imagine® software is used to map conservative signatures of water reflectances (e.g. Band 5 Digital Numbers (DN) 0 to 32 without shadow, or 0 to 28 DN when accommodating shadow influence) and affiliated shadow and greenness classes. Sequential classification with these signatures for each image enables the classes to be combined at a point using decision rules to produce an image (Grid) that depicts the frequency of inundation (derived in ArcInfo Grid®). The spectral class limits (provided in DNs) of the signatures listed in the order classified for each image are: for shadow and green vegetation TM Band 3 [0, 30], TM Band 4 [0, 105] and TM Band 5 [29, 59]; for open water TM Band 5 [0, 16] or [17, 32]; for residual shadow TM Band 3 [0, 16], TM Band 4 [0, 27] and TM Band 5 [0, 255].

The raw density sliced water body product may show some excessive water body classification (commission of non-water areas to spectral classes) or poorly joined or speckled features due to the characteristics of landforms and vegetation cover. These effects are reduced for mapping purposes by post-processing the data (Figure 1). Post-processing includes the reduction of topographic shadow, using slope models derived from the Auslig 9” Digital Elevation Models (DEMs), while ensuring features in hilly terrain such as reservoir features are retained through the use of a Geodata water body constraint layer.

A smoothing algorithm is applied to mapped zones of frequency of inundation using a pixel-count-thresholded interpolation function to estimate the inundation frequencies of incomplete or semi-enclosed water body edges (4 out of 8 pixels in a 3 x 3 focal filter must be classified as water body and the central pixel must be void). A despeckling process is applied to create a minimum connected water body size of 0.25ha. Grid attribute tables are updated to identify the year of water body occurrence, provide the map sheet name, and list the actual or interpolated frequency of inundation for any mapped water body feature. A colour table is inserted into the attribute table.

The grids are mosaiced into universal transverse mercator (UTM) zones (zones 54, 55 and 56). The zoned products may be combined with other raster layers prior to conversion to polygon coverages. Conversion to polygon coverage is required for map collation, editing and production purposes. The conversion process is described in Decision Rule 11 in the main text of the wetland mapping methodology.

This spectral classification and mapping method provides a robust process that delineates open and wet features across the majority of water body reflectances in terrestrial environments. The mapping process is clearly defined and open to evaluation and further analysis (refer to the density slice proformas provided in the technical specifications document). The process uses standardised program scripts (e.g. ArcInfo Arc Macro Language “AMLs”) to ensure consistent method application. More complex spectral classification approaches may be required for intertidal areas because of their complex characteristics of reflectance, but these areas are already mapped by vegetation and coastal mapping (e.g. regional ecosystem and tidal vegetation coverages) and are not a focal area for this mapping activity.

3. The Product

The development of the density sliced water body product has included statistical comparison with existing water body coverages (e.g. the DNR&M Queensland Murray-Darling Basin water body coverage by David Moffatt and Catherine Thrupp 2003), and accuracy assessment with unrectified and orthorectified aerial photography in inland and coastal environments. The density slice mapping method accurately defines the boundaries of water bodies at a scale of 1:100,000 (typically with a Root Mean Square Error less than 13m), but the reliability of the spectral classifications (class precision) varies with landscape characteristics between scene areas.

The precision of spectral classification is influenced most by topographic, vegetation and cloud features. The most persistent misclassifications are due to shadow cast by topographic relief and clouds.

Topographic effects persist because the scale of variation in topographic feature size is smaller than the DEM masks can accommodate or the DEM layers are not sufficiently accurate. Where high rates of spectral classification error due to topographic relief occur in arid or semi-arid environments, the total misclassification rates are largest. Conversely, the coarse DEMs may excise legitimate water features, including riverbeds and coastal flats.

Tall vegetation casts shadow and includes characteristics of moisture signatures, especially along wetland margins. Spectral class signatures are separated to minimise class confusion, but where shadow or green vegetation signals co-occur at a point with pure water signals in a temporal sequence, these affiliated classes are included in the estimate of inundation frequency. Large and dense cloud features may be classified separately to provide a layer to identify cloud shadow effects on spectral classes in the time series of density sliced water features (Knight 2004a).

4. Knowledge Base and Principles for Water Body Mapping Using the Density Slice Technique

Goal

To map exposed water body features that are located in intertidal and inland areas and are identifiable with existing State owned satellite data at a minimum spatial scale of 25m, in a consistent, repeatable and accountable manner across the State of Queensland.

Hypotheses

1. Open or identifiable water body features, at a scale of 25m diameter, have specific spectral characteristics that separate them from other landscape features.

    - Issue: feature mixtures and competition with shadow effects occur, and identification precision will vary with the characteristics of the data.

2. The specific water body spectral characteristics that accurately identify water presence are near-stationary through time and can be applied repeatedly through time.

    - Issue: changes in purity of spectral signal with satellite platform and age, and high potential variation in values due to environmental and scene conditions.

3. The most pure Landsat TM water signature information is found in the near-middle infrared spectrum.

    - Issue: more definitive signatures may occur for different spectral bands for different scenes or times of application.

4. The majority of interfering or competing spectral information can be excluded (filtered) or explained by slope models derived from the most accurate and available Digital Elevation Models

(DEMs) without significantly reducing the accuracy of natural open water body detection at a scale of 25m or larger.

Where undesirable exclusions of water body signatures occur due to DEM use, these effects are minimised through the use of Geodata (Series 2) water body coverages that identify the occurrence of artificial impoundments and lakes to enable signature mapping.

- Issue: scale dependent effects may need spatial functions to smooth and aggregate features of interest.
- Issue: the accuracy of DEM effects depends on DEM cell size and DEM spatial control.
- Issue: artificial reservoirs suffer greater reduction in extent with increasing distance upstream into steeper terrain. The Geodata coverages may not be sufficiently accurate and contemporary to account for all reservoirs and their true wetted extent.

5. The accumulation and combination of water body frequency information for every point of an identified water body increases the accuracy of the determination of water body spatial characteristics.

    - Issue: ephemeral and poorly connected wetland features may show spatial shifts through time, which is also an outcome of feature structural heterogeneity and signal dilution.
    - Issue: combining different spectral classes through time may reduce the locational precision of feature identification.
    - Issue: output values that are interpolated frequency values are truncated integers, and the spatial extent of these features may be offset from the original feature.

6. Rules-based smoothing of water body features to interpolate the frequency of missing edge values, followed by the removal of small and isolated features (less than 0.25ha in area), is required to enable the production of meaningful polygon coverages with meaningful attributes.

    - Issue: frequency information needs to be compiled, including the identification of the year of the image for which wetting is detected, and these data must be available for interpretation and to enable the evaluation of the effect of smoothing on estimated frequencies and their spatial distribution.

Decision/action rules for the application of hypotheses, listed sequentially

Note: These rules are applied in the order presented after a sufficient amount of image pre-processing, such as image rectification, spectral calibration and spatial clipping. Refer to the procedure-schematic (Figure 1) for a broad overview of method application, and the section “Summary of procedures for waterbody mapping using the density slice technique” in the technical specifications document for more detailed information including links to ArcInfo AML files.

1. Apply the multi-dimensional density slice: Band 3 [0,30], Band 4 [0,105] and Band 5 [29,59] to account for shadow and vegetation greenness effects prior to slicing water feature classes. Almost

all shadow and greenness effects will be trapped by this spectral class and will be removed by the application of DEMs.

> Note 1: This signature class sets a maximum limit for water signatures in Band 5 at 28 digital numbers (DN) when feature mixtures occur, although vegetation / shadow feature mixtures are allowed to extend to 59 DN, a level determined through prior empirical investigations.
>
> Note 2: The resulting spectral class is available for combining with water body classes when they co-occur at a point.

2. Apply the core water body spectral class (a density slice) of Band 5 [0,16] irrespective of the values of other spectral bands.

> Note 1: This spectral class will repeatedly identify deeper or more permanent water bodies. This spectral class is one of two water body density slices.

3. Apply the second water body spectral class (a density slice) of Band 5 [17,32] irrespective of the values of other spectral bands.

> Note 1: This spectral class is a little less accurate in application and will detect shallower and more ephemeral water features.
>
> Note 2: The upper threshold of 32 DN applies if feature characteristics have propagated through the greenness/shadow signature class.

4. Capture any remaining darkness effects through the use of a multi-dimensional density slice of Band 3 [0,16] and Band 4 [0,27], irrespective of Band 5 values.

> Note 1: This spectral class captures any residual shadow or water spectral effects, and it is available for combining with water body classes when they co-occur at a point.

5. Use a slope model derived from the most accurate DEMs available to remove classified features from areas of slope greater than a threshold of 1.5454545 degrees (25m Grid) or 1.0 degree (9” Grid). Additionally, constrain the effects of the slope model to areas not mapped by Geodata Series 2 water body coverages for features identified as human made or as lakes. This step requires pre-processing of Geodata sheets to produce a rectified and gridded (25m pixel) layer for the features and area of interest.

> Note 1: The DEM excisions may remove areas of upper catchment reservoir surfaces that are not delineated by the Geodata coverages.
>
> Note 2: DEM quality is not constant, and joins between different DEMs may be apparent through their filtering effects. This requires adaptive management, such as threshold reduction, spline interpolation of slope values for each classified pixel, or variations to the application of merge procedures (if required). Note that spline interpolation of slope grids may induce misclassification of water features along the map cut-line, though this effect is usually very negligible.

> Note 3: There is no location-specific yet generalised technique to completely separate water and shadow signatures. In application, the slope model is applied before assigning frequencies of spectral class occurrence at a point.

6. Combine classes from steps 1 to 4 with a dynamic link to step 5, for any point that includes an occurrence of a water body class, and calculate the total frequency of occurrence of classes.

   > Note 1: This step enables the inclusion of intermittently wetted water body margins into the accepted water body feature.

7. Perform smoothing (interpolation) procedures to provide the best possible map data base at a minimum scale of 0.25ha. This is achieved using a 3 X 3 neighbourhood focal function of equal weights (1,1,1) when at least four real-valued pixels are in contact by at least one corner point, but a “no-data” value occurs at the focal point.

   > Note 1: While the edge smooth and in-filling results are beneficial for polygon production and attribution, the output frequencies will not always correspond with the occurrence of source classes.

8. Despeckle small and isolated classified pixels/clumps using eight connected neighbour clump and 0.25ha threshold parameters.

   > Note 1: Valid information is lost in this process along with spectral classification noise.

9. Identify the location of major cloud masses to assist the evaluation of shadow effects on the distribution and frequency of water body features. This involves the use of a multi-dimensional spectral slice (Band 3 [110, 255], Band 4 [145, 255] and Band 5 [175, 255]) and the application of decision/action rules 6 to 8.

10. Provide adequate source information for water body feature interpretation. This requires the application of the Grid combine function to identify the contributing years for each frequency of water body occurrence.

    > Note 1: The interpolated frequencies of inundation do not always correspond to source feature occurrences. The attribute table is built to make the differences between the source and derived frequencies apparent, both through the listing of source and derived frequencies, and the year of capture of the intersected source classification data.

Assumptions

1. Spectral variation due to variable atmospheric, solar elevation / azimuth and sensor conditions can be accommodated within the bounds of the prescribed multiple classes, and through the application of Digital Elevation Model and Geodata (series 2) masks and areas of interest.

2. Three-band imagery (Red, NIR and near-MIR) is sufficient for water body mapping purposes.

3. The target water body spectral characteristics will always fall within the prescribed density slices, and if required, the more liberal density slice (Band 5 [17,32]) can be sacrificed to ensure a more conservative outcome. (Note that a Band 5 DN of 25 is generally considered the average maximum threshold for pure water features in the literature.)

4. The majority of cloud spectral characteristics will always fall within the prescribed signature limits, and when they do not, the cloud cover is not sufficiently dense to significantly influence the identification of water bodies and the calculation of their frequency of occurrence.

5. Available SLATS imagery provides a consistent data base of comparable data that is obtained at regular time intervals for similar climatic and seasonal conditions.

6. Undesirable effects due to cloud shadow or massive flooding is unlikely.

7. Classified and smoothed features can be converted to meaningful polygon features and attributed or edited as required.

8. An experienced GIS and remote sensing computer operator will be able to manage the operation of the spectral classification and mapping procedures.

9. Classified features can be readily ground truthed by vegetation management officers or other trained professionals, or validated with orthorectified aerial photos at a scale of 1:50,000 or larger (e.g. 1:25,000).

10. There are no implicit biases in the procedures that will influence the accuracy of application through time and across the State of Queensland.

Caveats

1. Procedures are designed to enable incremental improvements as feature/spectral information improves.

2. Total confidence in the accuracy of the mapped features and their frequencies of occurrence will only be obtained through systematic and representative ground-truthing in the year and season of image capture.

3. Small water body features or unusual spectral characteristics will be associated with reduced rates of water body feature identification and associated inundation frequency information.

4. A 25m pixel may overestimate the size of open water body features that occur at a similar or smaller scale.

5. Smoothing-in internal water body voids and despeckling, while setting a minimum mapping scale, will result in a small reduction of both valid information and spectral noise.

There is no guarantee that procedures based on Landsat TM platforms will be directly transferable to other sources of remotely sensed data, which may have smaller pixels and different boundaries to spectral bands.

5. References

Knight, A.W. (2004a) Summary of procedures for water body mapping using the density slice technique. Queensland Environmental Protection Agency, unpublished report, Brisbane.

Knight, A.W. (2004b) Knowledge base and principles for water body mapping using the density slice technique. Queensland Environmental Protection Agency, unpublished report, Brisbane.

Moffatt, D.B. and Thrupp, C.L. (2003) *The location and permanence of waterbodies in southwestern Queensland (Australia) – preliminary digital GIS data from Natural Heritage Trust project 972975*. Department of Natural Resources and Mines, Toowoomba.

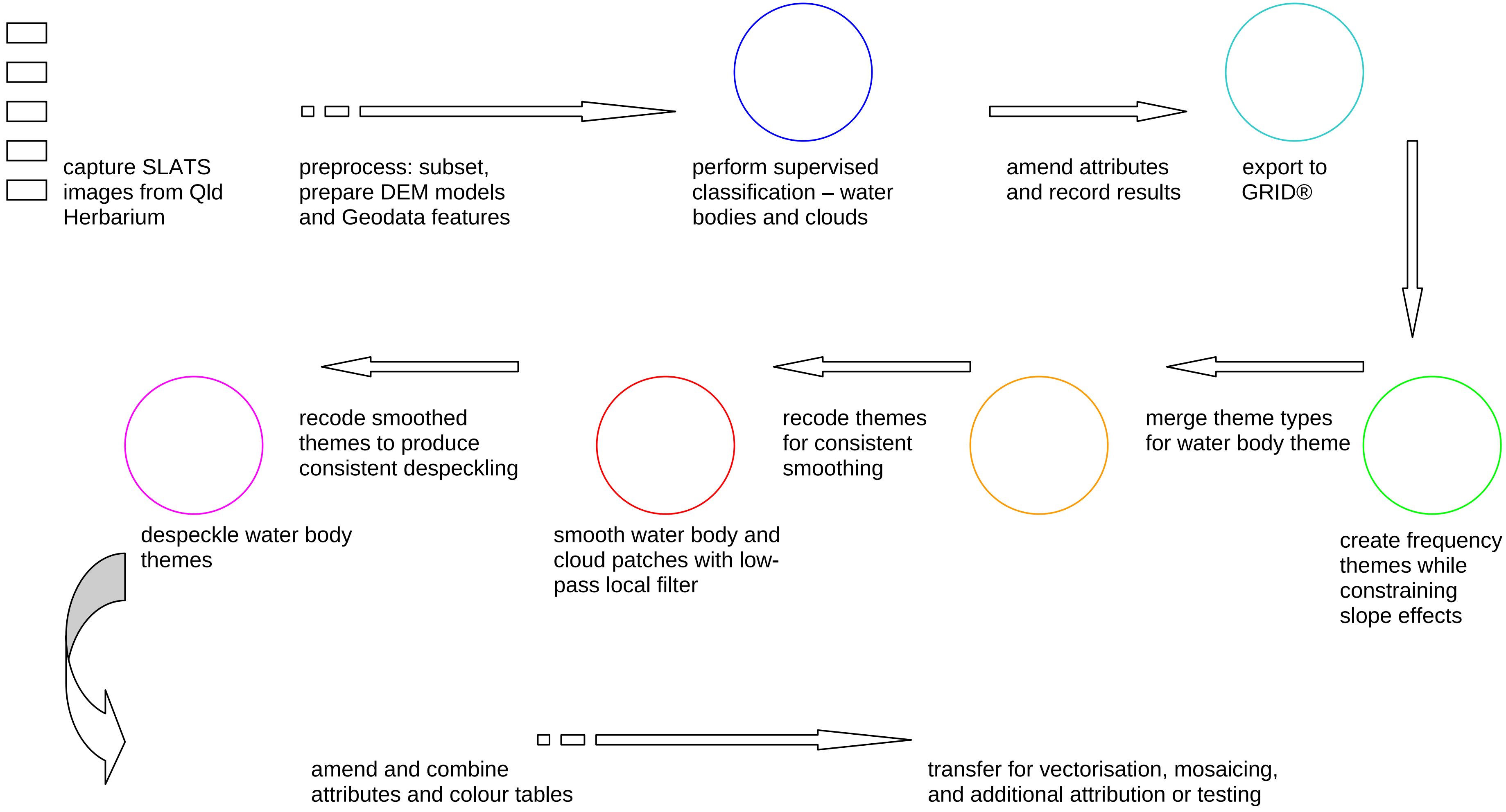

Figure 1. The general procedure for density sliced water signature mapping