APPLYING REMOTE SENSING TO MANAGING IMPACTS OF DIFFUSE SOURCES OF POLLUTION DUE TO LANDUSE CHANGE IN TWEED CATCHMENT, NSW, AUSTRALIA

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Abstract
There is growing evidence to suggest that diffuse sources of pollution contribute substantially to downstream water quality problems. This together with a rapid expansion of urban areas necessitates a new approach to managing water quality on catchment and tributary scales. Ability to assess nutrient emissions from existing diffuse sources and those resulting from land use change over time is essential to assist managers in reviewing effectiveness of the existing strategies and in developing better long-term planning and improved management practices.

A detailed land use classification suitable for diffuse pollution modelling is required to identify pollution sources and to quantify their relative contributions. A fused satellite imagery classification method based on integrating multiple data sources has been used to map existing and historical land use types in the Tweed catchment (Northern NSW, Australia). The land use classification results for 1982 and 2002 have been tested to estimate nutrient emissions on a spatially distributed basis and to delineate risk areas throughout the Tweed catchment. This study has provided nutrient loading information necessary to develop planning strategies and abatement measures that could deliver environmentally sustainable outcomes.

Additional Keywords: image interpretation, catchment management, L-THIA

Introduction
Residential and commercial development rapidly spreading into surrounding rural and undeveloped land impacts on the environment and results in loss of natural vegetation, open space and agricultural land. It also contributes substantially to degradation of stream ecosystems and deterioration of water quality in receiving waters (Walsh, 2000). Regional assessments of historical and contemporary land use change are needed to anticipate the impacts associated with the change and to develop abatement measures that will lead to environmentally sustainable practices.

Land cover and land use changes can be substantial but are difficult to quantify when they occur incrementally. Recently, data from satellites has been widely used to illustrate the rates at which land use changes are occurring. Temporal mapping from satellite data has demonstrated effectiveness of integrating existing maps with remote sensing data and relevant auxiliary geographic information to dynamically map land use characteristics for a large area (Hurd *et al*., 2001; Civco and Hurd, 1999). Land use maps from satellite data not only provide a strong visual means for identification of growth areas, but also supply essential information on how the progress of urbanization and land use change affect pollutant emissions to waterways and, subsequently, ecosystem health.

The Tweed catchment has been developed at an increasing rate for the last twenty years. A project has been undertaken to analyse land use changes in the Tweed catchment and to link these to changed nutrient exports. A companion project will assess their cumulative impact on coastal waterways. Long-Term Hydrologic Impact Assessment (L-THIA) model has been used to predict changes in runoff and Non-Point Source (NPS) pollution from catchments. The runoff volumes are predicted using the SCS Curve Number (CN) method, which uses precipitation, soil type, plant cover, and management practices to estimate runoff (Lim *et al*., 1999). L-THIA requires land use classes from integrated image interpretation to estimate catchment emissions of total nitrogen (TN) and total phosphorus (TP). This generated information provides insight into the relative hydrologic impacts of different land uses and land use changes. The results can be used to generate community awareness of potential long-term problems and to support planning strategies aimed at minimizing disturbance in critical areas and protection of natural resources.

Materials and Methods
Remote sensing methodology was used to define land use categories in the Tweed catchment. The land cover analysis was based on data from the Landsat series of satellites, which offer one of the most extensive and continuous terrestrial imagery archives. Images for 1982 were acquired from Landsat 5 Multispectral Scanner and for 2002 from Landsat 7 Enhanced Thematic Mapper. The acquired image data was then registered to aerial photos using ground control points to ensure they coincided accurately. The nearest neighbour method was used to

resample the images to the pixel size representing 25 linear metres. In order to minimise computer processing during image classification, subsets of the rectified images were created using Tweed catchment as a mask to intersect with the images. Figure 1 shows the location of the Tweed catchment on the NSW far North Coast and 2002 satellite image of the area.
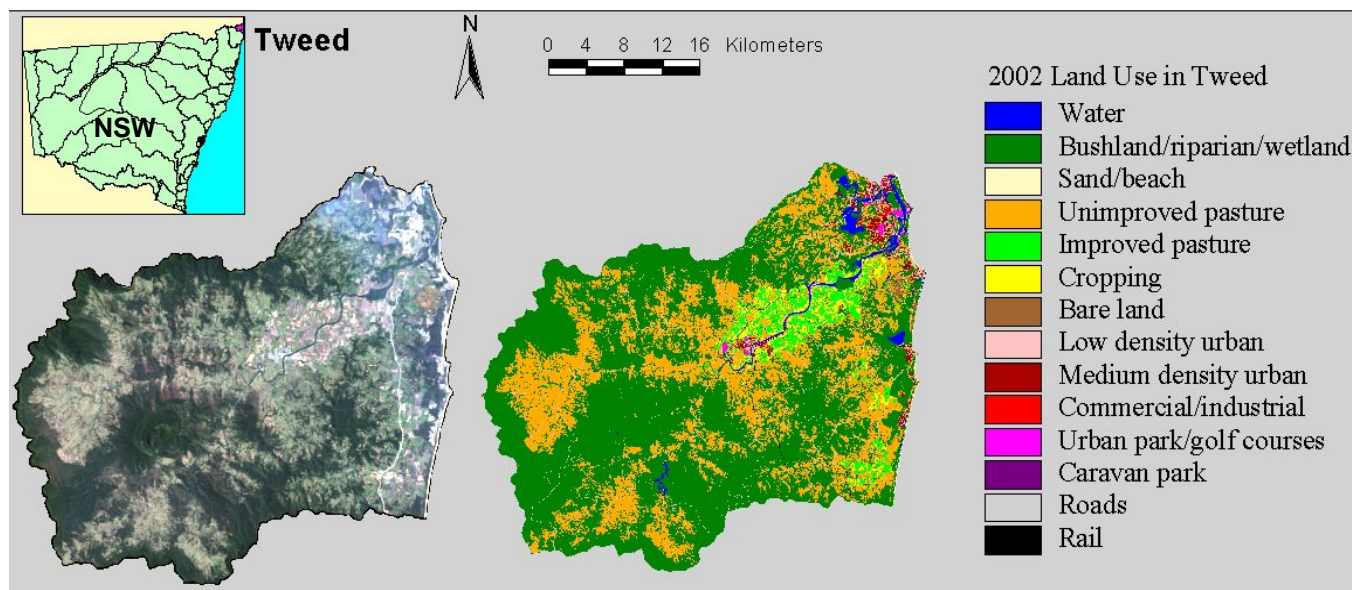

Figure 1. Pseudo true-colour satellite image of Tweed catchment and land use/land cover classification for 2002

In order to prepare a detailed land use classification map for L-THIA diffuse pollution modelling for each subset image, an unsupervised classification was performed using all bands to generate 100 classes based on statistical similarities in spectral characteristics exhibited by each pixel of the images. Each class was then assigned with a land cover label. This was done by visual comparison of the digital topographic maps of the area with the original Landsat image and further refined using 1-metre high-resolution aerial photos and a 4-metre resolution multispectral IKONOS image. This process resulted in a number of unresolved classes for which a subsequent reclassification was required to refine the doubt classes. Since the unresolved classes were separated into several groups during the visual verification process, further reclassification was based on each group of unresolved classes to eliminate ambiguous pixels. Each group of unresolved classes was used to mask with the original Landsat image to extract doubt pixels. Hybrid-supervised training signatures and auxiliary geographic information were then used to differentiate the doubt land cover classes derived from unsupervised classification and label the classes with the land use categories. The reclassification process was reiterated many times for all the groups of unresolved classes until a complete and satisfactory land cover/land use was achieved. After the classes were resolved, interactive on screen editing was performed to eliminate any apparent errors.

The auxiliary vector data of infrastructure, road and rail system and parks were converted to raster images and incorporated in the land use thematic map during the classification process. Since residential densities usually indicate increasing level of imperviousness in the catchment and have major implications for stormwater quality, the residential and development densities were differentiated in order to reflect different nutrient emission values. The industrial and commercial class was determined by on screen digitisation of the known areas comprising centralised shopping and industrial activities. Neighbourhood density analysis was applied to enhance resolution of the interpreted urban area and to delineate a broad urban category into 3 classes representing different development densities: high, medium and low (Figure 1).

The main limitation of the classification procedure was inability to conduct a traditional accuracy assessment because time and resource constraints prohibited acquisition of validation data. The assessment utility of Imagine 8.6 was used to report the percentages of correctly classified pixels. The overall reliability of the interpreted land use classification was assessed by comparing the land uses derived from remotely sensed data to other existing data sources including existing thematic maps and aerial images. Despite obvious temporal and spatial differences between the land use classification and auxiliary data satisfactory overall accuracy of 76.6% was achieved.

In order to input the land use classification from image interpretation into L-THIA modelling environment 14 land use classes in Figure 1 were aggregated to correspond with 8 generic classes in L-THIA and to reflect pollution potential of a particular land use. Annual TN and TP emissions were computed as a function of runoff volume and a predefined value of event mean concentrations (EMC) for each pollutant and each land use type. The EMCs in L-THIA were modified to better approximate the local conditions (Fletcher et al., 2003). The model was applied to estimate nutrient emissions for the rapidly urbanizing coastal area of the Tweed catchment, which is under increasing pressure of development (Figure 2). Three scenarios were examined including historical (1982), current (2002) and a hypothetical future development. For each scenario L-THIA was run with a 10-year rainfall record to characterize long-term nutrient exports from different land use patterns.
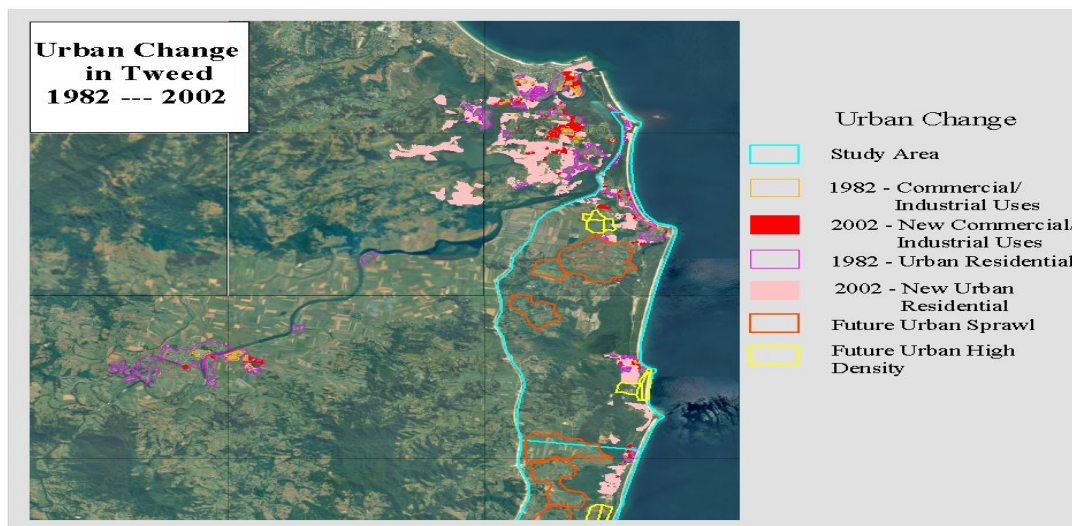

Figure 2. Urban change in the Tweed catchment between 1982 –2002

Results and Discussion
Table 1 shows the land use categories and land use change between 1982 and 2002. The results indicate that over the last 20 years natural and semi-natural land uses have been gradually decreasing giving way to land uses generating higher volumes of runoff and pollution such as urban residential, commercial/industrial, and transport. In 1982, only 0.9% of Tweed catchment was classified as urban while in 2002 the urbanisation reached 2%. The total urban change affected approximately 1400 hectares. Over the study period the Tweed catchment experienced strong growth in particular on the coastal fringes where the area of urbanised land uses increased by 6.5%.

Table 1: Land use change in the Tweed catchment between 1982 and 2002

Land Use Class	Land Use Area (hectares)		
	1982	**2002**	**Change 2002-1982**
Water	1834.4	1895.8	61.4
Bushland/riparian/wetland	80144.1	78631.6	-1512.5
Sand/beach	240.9	256.4	15.5
Unimproved pasture	38278.4	38002.7	-275.7
Improved pasture	4797.2	4463.4	-333.8
Cropping	2838.1	2795.2	-42.9
Bare land	170.1	563.8	393.7
Urban (low density)	521.2	664.1	142.9
Urban (medium density)	288.8	1292.3	1003.5
Commercial/Industrial/Urban (high density)	97.2	212.7	115.5
Park (urban) golf courses	247.6	302.7	55.1
Park (caravan)	45.7	44.7	-1.00
Roads and Rail	3184.8	3567.4	382.6

Figure 2 shows the expansion of built-up areas in the Tweed catchment. The polygons of new urbanised land uses are plotted over a 1-metre resolution digital aerial photography as a background to illustrate the landscape in the

catchment. The increase in built-up areas may have profound effects on rainfall-runoff relationship and pollutant loads primarily because of the change in the level of catchment imperviousness and the amount of runoff generated.

The estimated long-term annual loads of TN and TP for 3 land use scenarios in the study area are presented in Figure 3. In all scenarios tested, the loads of TN and TP were dominated by contributions from agricultural land uses reaching 77.1% of estimated total TN load and 84.1% of total TP load for the 2002 land use pattern. Urban areas increased from 563.8 to 3090 hectares from 2002 to the Hypothetical Future with corresponding increases in TN and TP loads of 26.8% and 19.3%. This shows that urban development can make a major contribution to nutrient exports and emphasizes the need for best management practices in urban design. Results also highlight that overall nutrient emissions may be minimized by preferentially accommodating urban development within areas where current land uses are associated with high nutrient export rates.
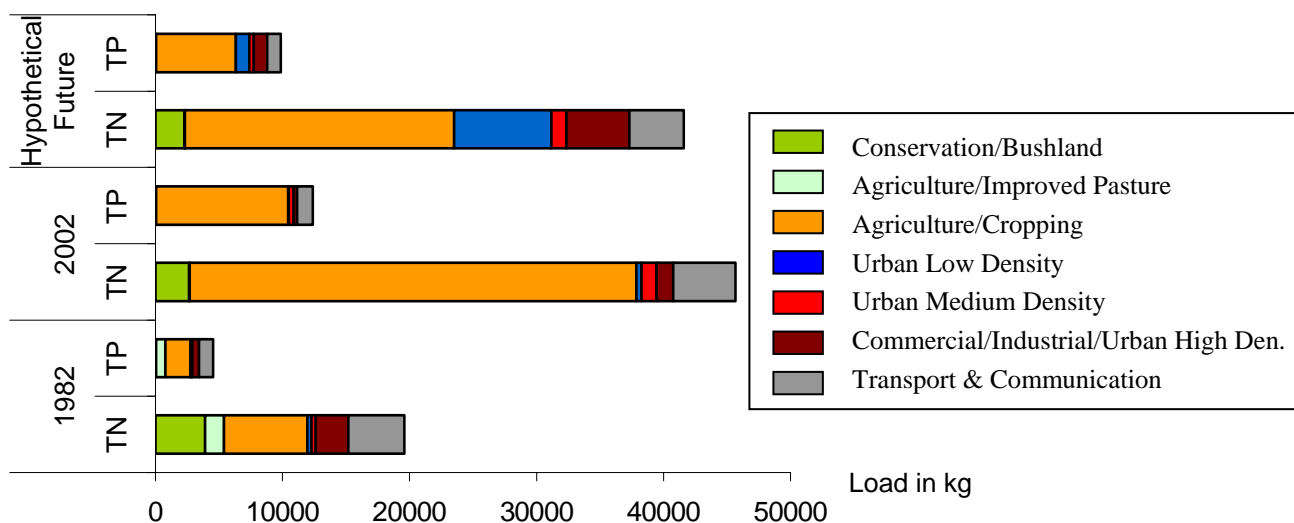

Figure 3. TN and TP emissions for different land use scenarios in the study area with hypothetical development

Conclusions

The foreshores of the Tweed and other coastal catchments are increasingly recognised as desirable locations for residential development due to the obvious scenic and recreational opportunities. With increasing pressure to further develop coastal fringes, environmental managers are posed with the unenviable task of assessing whether certain types or levels of development are sustainable in terms of their impact on the ecology of their associated water bodies. The use of the interpreted image classification approach to observe and assess trends in urban growth and the ability to develop linkage between land use change and nutrient export offers a powerful planning tool to assist with rapid estimates of nutrient emissions from spatially distributed areas in relation to sensitive waterways. An analysis of Landsat data for 1990 and 1995 has also been undertaken to provide a more detailed historical perspective on spatial patterns of land use and to establish the rates of change resulting from urban sprawl.

Acknowledgements

References

Civco, D.L. and Hurd, J.D. (1999). A Hierarchical Approach to Land Use and Land Cover Mapping Using Multiple Image Types. Proc. 1999 *ASPRS Annual Convention, Portland, OR*, pp687-698.
Fletcher T., Duncan H., Lloyd S. and Poelsma P. (2003). Stormwater Flow and Quality and the Effectiveness of Non-Proprietary Stormwater Treatment Measures. Unpublished Report, CRC for Catchment Hydrology, Monash University, Melbourne. 110pp.
Hurd, J.D., Wilson, E.H., Lammey, S.G. and Civco, D.L. (2001). Characterization of Forest Fragmentation and Urban Sprawl Using Time Sequential Landsat Imagery. *ASPRS 2001 Annual Convention, St. Louis*, MO. 13pp.
Lim, K.J., Engel, B.A. , Kim, Y., Bhaduri, B. and Harbor J. (1999). Development of the Long Term Hydrologic Impact Assessment (LTHIA) WWW systems. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds) "2001 Sustaining the Global Farm", pp1018-1023.
Walsh, C. J. (2000). Urban Impacts on the Ecology of Receiving Waters: a Framework for Assessment, Conservation and Restoration. *Hydrobiologia* 431(2), 107-114.