Project D210.

Urbanization and the
Ecological Function of Streams

**Methods for the determination of
catchment imperviousness and drainage connection**

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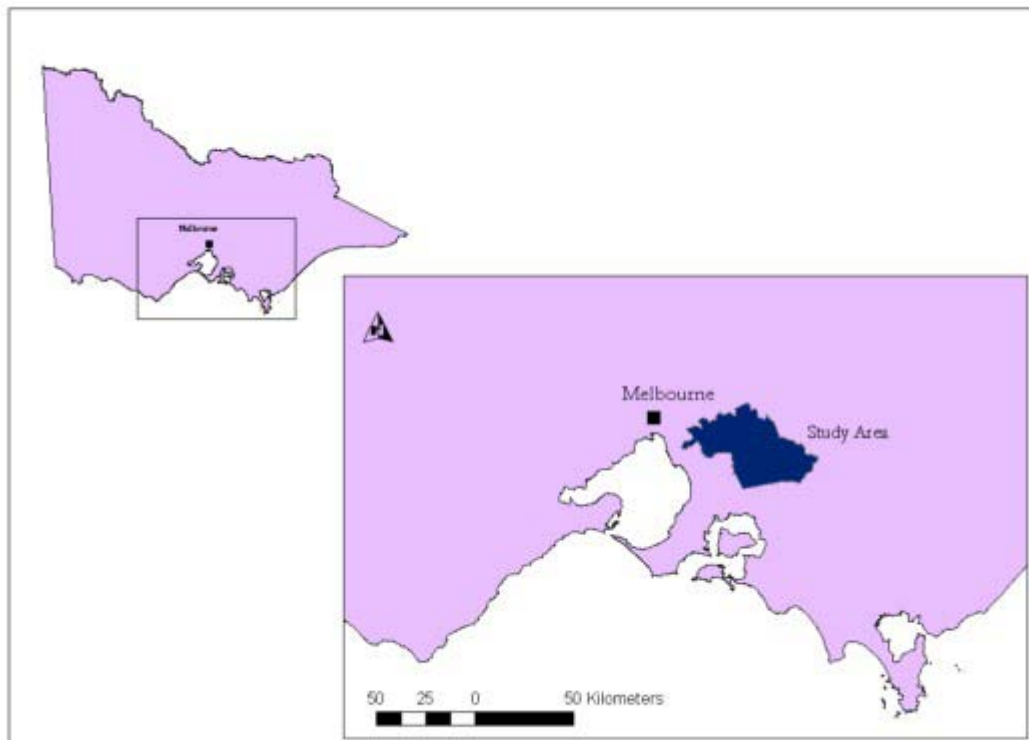*Monash University, Clayton 3800, Australia*

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Fig. 1. Outline of the study area for CRC FE project D210.

Introduction

Catchment imperviousness (the proportion of a catchment covered by hard surfaces impervious to water) and degree of stormwater drainage connection have been identified as central elements of urban design that impact upon receiving waters (Walsh, 2000). Catchment imperviousness is a useful neutral measure of urban density, while drainage connection is an indicator of the efficiency of water and pollutant transport from impervious surfaces to receiving waters.

CRC for Freshwater Ecology Project D210, 'Urbanization and the ecological function of streams', aims to relate a variety of in-stream ecological processes and indicators to these two urban attributes in catchments of small streams draining the hills on the eastern fringe of Melbourne, Victoria, Australia (Fig. 1). This paper reports on the methods used to build the spatial database of imperviousness and drainage connection for the study area. Appendix B is a user's manual for determining these variables for any designated area using the completed MapInfo® database.

Table 1. Data supplied (√ = digital data supplied) by local government authorities in the study area

LGA	Gross building area	Stormwater drainage
Knox City	unavailable	√
Monash City	√	√
Manningham City	unavailable	unavailable
Maroondah City	not supplied	not supplied
Whitehorse City	unavailable	√
Greater Dandenong City	unavailable	√
Shire of Yarra Ranges	√	√
Shire of Cardinia	unavailable	drained areas outlined manually

Data sources

Digital aerial orthophotography (Nov 1999-Feb 2000) for the entire study area was provided by the Melbourne Water Corporation (MWC).

The State Digital Road Network (SDRN) and the National Mapping Division (NMD) 1:25,000 topographic road map data were used to delineate road areas.

Land parcel and planning zone data were derived from the Victorian statewide cadastral map data.

For connection modelling 1m contour data from the MWC were used in the metropolitan area, stream and 10m contour data from the NMD1:25,000 topographic map data was used.

Data availability and quality varied between the 8 local government authorities (LGAs) that lie within the study area. Table 1 outlines the data supplied by each of the LGAs for the study.

MWC also provided data delineating their main drains and waterways.

Deriving the impervious surface layer

A flow path for the derivation of the impervious layer is presented in Appendix B. Impervious surfaces were treated as three separate categories—buildings, roads and carparks.

Buildings Layer

The buildings layer was derived from either gross building area data (where available) or from aerial orthophotographs.

Where the LGA's valuation database included locations of building points, polygons representing each building were directly plotted. Otherwise, the building area data was geocoded using a unique key field linked to the land-parcel data set.

In the initial building of the data set, a buffer of 1.1 times the recorded area was set to allow for eaves, paved areas and non-registered buildings. A preliminary ground-truthing found this to be an underestimate for the study area, and a correction factor of 1.5 was applied to building areas. A more systematic ground-truthing is required to assess the accuracy of this correction factor for the entire study area.

Where LGA data was not available, building areas were digitized manually from the orthophotographs. Manual digitization entails the identification of each building from the orthophoto, and on-screen tracing of the building to produce a polygon. In less densely developed areas, such as Cardinia City, all visible building areas were digitized manually.

In the densely developed areas of Manningham, Maroondah, Knox, Whitehorse and Greater Dandenong cities, a sampling approach to digitizing was taken. From visual inspection of the orthophotographs, blocks of suburbs were designated as relatively homogeneous in regard to the size of residential buildings. A random sample of 150 residential houses was digitized manually in each block (determined in a pilot study to be an adequate sample size for an estimated mean area with a precision of 0.05, where precision = standard error/mean). The mean residential house area was applied to the centroid of each land parcel as derived from the cadastre to produce a polygon of the appropriate area (Fig. 2a, b).

Each land parcel was visually checked for a match between the generated polygon and a building. Where no building was present in the land parcel, the polygon was deleted. Where the land parcel contained a non-residential building, the generated polygon was replaced by manually generated polygons (Fig. 2c).

a) centroids from land-parcel data

b) buffers applied to produce polygons

c) automatic generation of polygons checked, manual digitization

Fig. 2. Process of building area estimation in densely developed areas without existing data

Roads Layers

This layer was derived from both the SDRN and 1:25,000 scale topographic road layer. Both datasets were necessary because the SDRN data does not categorize roads as sealed or unsealed, while the 1:25,000 scale road layer is not current. Therefore, current data from SDRN was combined with sealed and unsealed information from topographic road layer. Road lines were used to produce buffers that represent the total area of the road surface. Final categorization of road surface was assessed by ground truthing.

Mean road widths were estimated for each SDRN category (e.g. highway, freeway, street, road, avenue, etc.) by on-screen sampling using the orthophotographs. Road centrelines were buffered by a radius of half the estimated road width (Fig. 3).

Ground truthing found road widths outside in the Metropolitan area were consistently overestimated in the initial buffering process, and a correction factor of 03-0.6 was applied depending on the road category.

Sealed and unsealed roads were kept as separate layers to permit the calculation of imperviousness with and without unsealed roads. It could be argued that unsealed roads do not have the same hydrological (and water quality) effect of sealed roads.
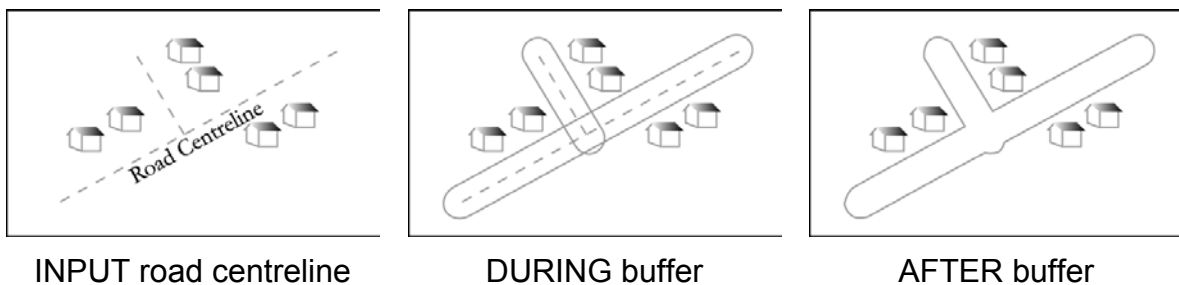

| INPUT road centreline | DURING buffer | AFTER buffer |

Fig. 3. Road buffer processing.

Carpark Layer

Finally, carparks and other paved surfaces were manually digitised.

Estimation of drainage connection

Defining connection

Leopold (1968) attempted to quantify the degree of drainage connection by estimating 'the proportion of basin [catchment] with storm sewers [stormwater drainage pipes] and improved channels'. In this study, we reduced the correlation between catchment imperviousness and drainage connection by considering only the impervious areas (as opposed to all land surfaces) that are directly connected to stormwater pipes draining directly to receiving streams. From such data, a calculation of the proportion of impervious areas that are directly connected to receiving waters (connection) can be calculated for any catchment.

In many areas of Melbourne, directly connected suburbs are easily identifiable from drainage maps. In other areas, particularly in the urban fringe and beyond, some impervious areas are drained by stormwater pipes, but these in turn drain to dry earthen or grassed channels or to unchannelized dry land. In such areas, a binary classification (connected or unconnected) is obviously an oversimplification. The methods developed here attempted a binary classification of such areas by assessing the runoff ratio of the land below the stormwater pipe outlet. Where the runoff ratio was classified as low, the impervious areas upstream were considered unconnected.

This classification system is being developed further using hydrological models (e.g. (Fletcher et al., 2001) to estimate a degree of effective connection for different drainage systems (rather than a binary classification). Degree of connection could also be divided into several categories: e.g. hydrological connection and connection for several size fractions of pollutants. However, for the purposes of study design in project D210, a binary categorization of connection was employed.

Data integration and validation

1) A cohesive hydrology network was established using LGA drainage data, MWC underground pipes and channel data and NMD stream data.

2) Planning zone data was used to make an initial division based on the assumption that areas zoned as Environmental Rural Zone (ERZ) will not be connected.

3) Further classification of non-ERZ areas was made based on the availability and quality of drainage pipe data.

   a) Areas with full pipe data coverage showing drainage directly to streams on trunk drains were classified as connected.

   b) Areas where the pipe network was connected to other pipes or streams, but the pipe data was incomplete, so that some enclaves appeared unconnected were classified preliminarily as ambiguous.

   c) Areas with a pipe network designed to solve local drainage problems such that pipes are not directly connected to streams were classified as unconnected.

   d) Areas for which inadequate pipe data were available were preliminarily classified using the advice of LGA engineers, but these classifications were re-assessed (below)

4) Ambiguous areas (b and d, above) were re-assessed using slope and aspect information from topographic data. A two-class map was produced, separating slopes into high (≥4%) and low. High slopes were sub-divided into eight aspect categories. Where overland flow distance to stream was all along a high-slope path, the drained area was classified as connected.

5) Classifications of ambiguous areas were ground-truthed and re-classified where necessary.

The output of this process was a single layer of polygons classified as connected or unconnected. Combining this layer with the imperviousness layers, permitted classification of each impervious polygon. (see Appendix B for explanation of this process)

References

Fletcher, T. D., Wong, T. H. F., Duncan, H., Jenkins, G. A., & Coleman, J. (2001) Managing impacts of urbanisation on receiving waters: a decision-maiking framework. In *Proceedings of Third Australian Stream Management Conference.* (ed I. Rutherfurd), Cooperative Research Centre for Catchment Hydrology, Brisbane, Qld.

Leopold, L. B. (1968) *Hydrology for Urban Land Planning: a Guidebook on the Hydrological Effects of Urban Land Use.* Circular 554. U.S. Geological Survey, Washington D.C.

Walsh, C. J. (2000) Urban impacts on the ecology of receiving waters: a framework for assessment, conservation and restoration. *Hydrobiologia*, **431,** 107-114.

Appendix A. Workflow path for determination of imperviousness
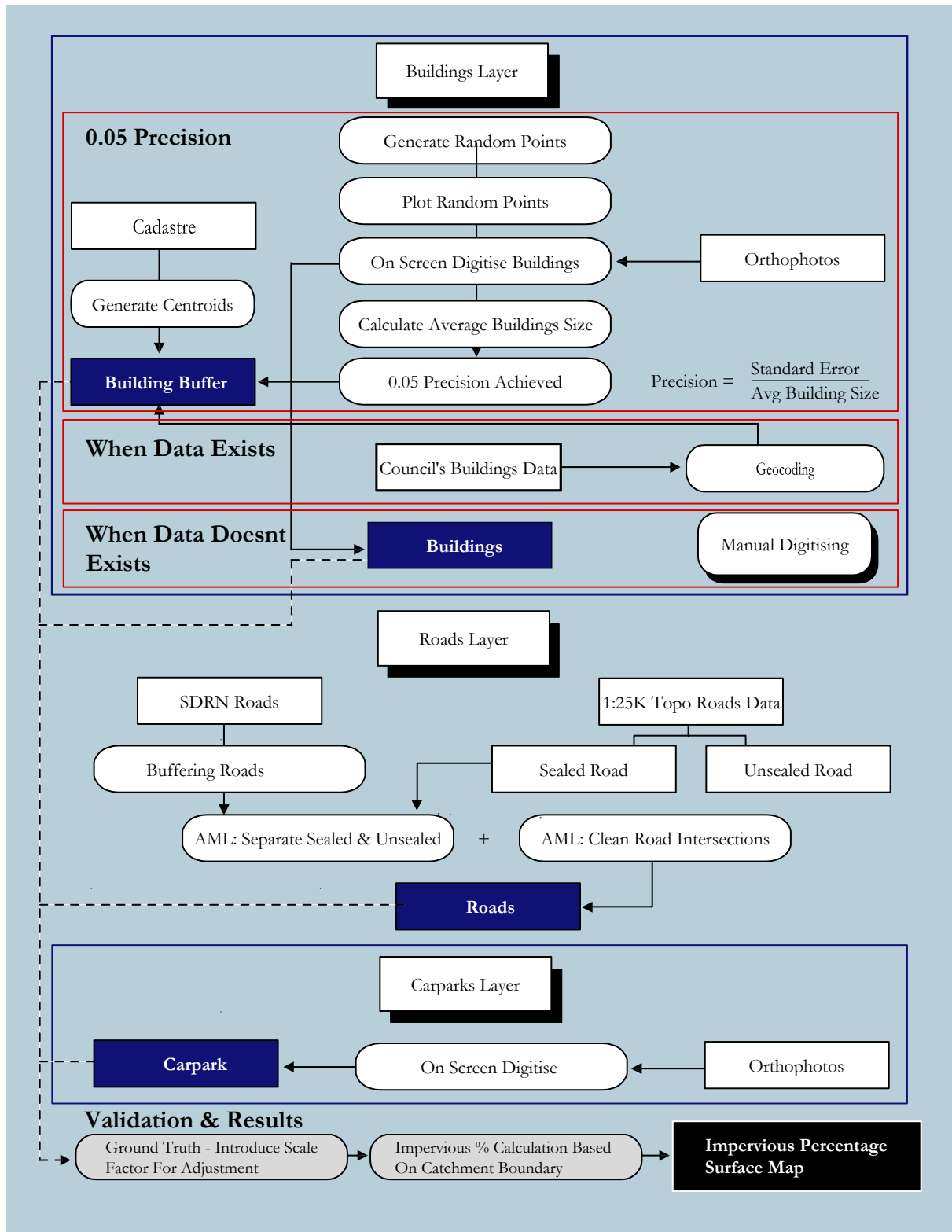
Appendix B. D210 spatial database. User's manual

Accessing the data

The D210 spatial database resides on the shared drive accessible to all Monash team members (directory '*D210\Spatial data*'). Team members without access to that drive should contact Chris Walsh. The database consists of four primary MapInfo layers that should be opened from MapInfo.

1. *\catchment data\Buildings*
2. *\catchment data\Sealroads*
3. *\catchment data\Unsealed roads*
4. *\catchment data\Connected area Aug 01*

Additional layers that may prove useful include

d210 subcatchments (180 sub-catchments delineated in the process of site selection)
d210 final subcatchments (sub-catchments of the 16 study sites)
\catchment data\MWC Waterways (drainage lines for streams in the study area)
\catchment data\YVW STPs (locations of STPs in the study area)
\contours\79222_contours and *\contours\79223_contours* (10 m contours for the study area)

Calculation of catchment imperviousness

1) Delineate the catchment(s) of interest. d210 subcatchments will be a useful template for this purpose. These subcatchments have been derived using 10m contours, MWC and LGA drainage lines. Alterations to the already delineated catchments are best made using the contours and waterways layers listed above.
   One of several ways to do this is to
   <Map – layer control>
   Select cosmetic layer and make it editable by checking the 'editable' box (pencil icon).
   Close the layer control dialogue box and select the 'polygon tool'.
   Use the waterways and contours as guides to produce a new polygon.
   If you wish to trace an existing subcatchment, press the S key, which will turn on snap mode (S again to turn it off). Snap mode, snaps the cursor to existing nodes.
   Click on one node of the target subcatchment (ensure it is snapped first, the cursor should turn into large dashed cross).
   Pointing to another node on the same polygon and pressing the shift key will trace the shortest path around the polygon.
   Pressing the Control key will trace the longest path.
   Using this method, a complex polygon can be traced with 3 mouse clicks.

   Once the desired polygon(s) have been produced, save them by
   <Map – save cosmetic objects>

2) Make the catchment polygon editable
   <Map – layer control. Select the new catchment polygon layer and check the 'editable' box (pencil icon)>
   and convert it into polylines
   <Query-Select-Records from table-(the catchment polygon table)>
   <Objects – convert to polylines>

(save this object as a new file with a new name *<File – save copy as- 'catchment polylines'- save table>*).
If necessary (if some polygons have been deleted), *<Table-maintenance-pack table-'catchment polygons'>*
<File close 'catchment polygons table'>
<File open table 'catchment polygons'>

3) Make the buildings layer editable. Run an SQL query to select the buildings that intersect with the newly created polyline.
<Query – SQL select, select Tables Buildings and 'catchment polylines', where condition Buildings intersects catchment polylines>
(This selects just those buildings that are on the boundaries of polygons and therefore drastically improves calculation time for the next bit)
<Objects-set target>
Select the polygon object(s). *<Query select table 'catchment polygons'>.*
<Objects-split> set all fields to method = VALUE, except IMPAREA_M2, which = Area proportion*
(This makes sure that any polygons spanning two catchments are only proportionately counted in each catchment).

4) Do the same for sealroads (and for unsealed roads if this layer is to be included in imperviousness estimate).

5) Modify the structure of the 'catchment polygons' table (if this has not already been done)
<Table-maintenance-Table Structure>
and add the following columns (as type = float):
carea,
buildings,
sealedroads,
unsealedroads (if including)
imp.

6) Open up the catchment table again and
<tables-update column>
Table to update-'catchment polygons'
Column to update* This step will need to be repeated for each of a) to e) below. For each column, make sure that the column to update entry is correct before pressing OK. Mapinfo will default to adding a temporary column when values are being calculated from a second table.

   a) carea: value = Area(obj, "sq m")

   b) buildings: (get value from Table Buildings, where object from table buildings is within obect from table catchments)
   sum of expression = ImpArea_m2*Correction_factor

   c) sealedroads: same as for buildings, but from Table Sealroads and expression = ImpArea_m2/Correction_factor

   d) unsealedroads: same as for sealedroads

   e) imp: value = (buildings + sealedroads)/carea or
   (buildings + sealedroads + unsealedroads)/carea

7) The completed table can be exported by saving as an access database.

Calculation of connection

Each polygon in the buildings, sealroads, and unsealed roads tables has been classified as connected (1) or not (0) using the connected layer. These values are recorded in each table under the field 'connected'.

1) Modify the structure of the catchment table
   <Table-maintenance-Table Structure>
   and add the following columns (as type = float):
   connbuildings,
   connsealedroads,
   connection
   (no unsealed roads are classed as connected)

2) Open up the catchment table again and
   <tables-update column>

   a) connbuildings: (get value from Table Buildings, where object from table buildings is within obect from table catchments)
      sum of expression = ImpArea_m2*Correction_factor*connected

   b) sealedroads: same as for buildings, but from Table Sealroads and expression = ImpArea_m2*connected/Correction_factor

   c) conn: value = (connbuildings + connsealedroads)/(buildings + sealedroads) or (connbuildings + connsealedroads)/(buildings + sealedroads + unsealedroads)

3) The completed table can be exported by saving as an access database.

Note that all these calculations have been conducted and saved in the d210 subcatchments table.