Module 7

Imperviousness

7.1 Purpose

Imperviousness has emerged as a key indicator for urban watershed management. It is an integrative indicator, and can be used to estimate or predict cumulative water resource impacts. Having reliable estimates of imperviousness for watersheds in the Georgia Basin will be very useful in developing watershed protection strategies. Previous work has described and compared methods for determining imperviousness (Zandbergen et al., 1999); this has suggested the need for a sufficiently accurate and consistently applied methodology that can be used by local governments, resource managers and community partners.

The objectives of this module are to:

- Map local watersheds for imperviousness;
- Contribute to the use of imperviousness as a key indicator in watershed protection;
- Promote the use of a consistent methodology for measuring imperviousness;
- Make imperviousness mapping more accessible to local governments and community groups.

The audience intended for this module include:

- Staff in municipalities (planners, engineers).
- Community groups involved in watershed mapping.
- Colleges, universities and other educational institutions.
- Staff of resource / environmental agencies.

7.2 Final Products

A completed watershed imperviousness overview should generate the following products:

- A table with land use and cover categories considered and imperviousness factors used.
- A 1:5,000 map including overview watershed features (watershed boundaries, sub-watersheds, watercourses, roads, cadastral, topography) and mapped imperviousness land attributes including land use and cover and estimated. total impervious area (TIA) and effective impervious area (EIA).

Use of imperviousness information

Watershed classifications

Imperviousness information can be used for comparing watersheds within a region, or to compare one watershed with a general classification. This assists in setting conservation priorities, developing regional management strategies, and setting watershed objectives etc.

Comparison with other watershed health indicators

In-stream measures of watershed health (e.g. water quality, biota, and habitat) can be related to levels of imperviousness, and compared with relationships from other studies. This provides insight into the overall impact urbanisation is having on the aquatic ecosystem.

Evaluating urban design

Different designs for newly developing areas or re-developing areas can be compared in terms of their potential environmental impacts using imperviousness estimates for these areas. The increases can be placed in the context of the overall degree of the existing development of the watershed.

Build-out analysis

Looking into the future of a community can be accomplished by determining the imperviousness that could result from development according to the existing zoning plan. Relating this to the (potential) impacts of that level of imperviousness can provide some insight into what the watershed will look like if the existing zoning plan is implemented.

7.3 Introduction

7.3.1 Methodology

While a brief summary and comparison of methodologies will be presented, the emphasis will be on developing land use and land cover maps at a scale of approximately 1:5,000 using orthophotos (or aerial photos). This approach is considered the most useful level of analysis for the information to be useful for sub-watershed planning, stormwater management, and municipal land use planning.

7.3.2 What is imperviousness and why is it important?

Imperviousness has been identified as a key indicator of general watershed conditions. Numerous studies have documented declines in the health of streams and rivers with increasing levels of imperviousness. The impervious area in a drainage basin provides a quantitative measure of the potential impacts on hydrology and other stream health conditions. It is a measure of the total area where water does not infiltrate into the soil. Impervious areas in urban regions include: roads, rooftops, sidewalks, patios, roads, parking areas and highly compacted soil.

Impervious areas are major contributors to the environmental impacts of urbanisation. As the natural landscape is paved over, a chain of events is initiated that typically results in degraded water resources. Imperviousness is an integrative indicator, and can be used to estimate or predict cumulative water resource impacts. While a good understanding of the watershed health requires information on many in-stream conditions (including hydrology, water quality, physical habitat and biota), imperviousness is probably the most meaningful indicator for the general condition of stream ecosystems.

Recent research in various regions has consistently shown a strong correlation between the imperviousness of a drainage basin and the health of the receiving stream. While the impact of imperviousness on the health of streams has been recognised for many decades, the last few years have seen a much stronger recognition of the importance of imperviousness as an integrative indicator. Several authors have proposed to use imperviousness as a unifying theme for urban watershed management (Schueler, 1994; Arnold et al., 1996).

Research on small lowland streams has shown that hydrologic change creates immediate and severe negative effects in the early stages of urbanisation. Even at very low levels of imperviousness, these changes can cause profound alterations to in-stream flow conditions, stream channel conditions, riparian and in-stream habitat conditions, which leads to a reduced ability of streams to support healthy fish populations. A threshold of 10% total imperviousness has been suggested by several studies. Water and sediment quality become an additional concern at higher levels of imperviousness, although localised water quality problems can already occur at low levels of overall watershed development, for example pesticides from residential areas, sediment from development sites or agricultural runoff.

Imperviousness is a very important watershed indicator from a scientific perspective:

Imperviousness correlates highly with changes in hydrological indicators base-flow, peak-flow peak-flow/base-flow ratio, and flooding frequency. As such, it can be used as a surrogate for hydrological monitoring and modelling where no such information is available.

Imperviousness correlates highly with pollutant loading from non-point sources in urban areas. As such, it can be used as a surrogate for stormwater loading monitoring and modelling where no such information is available.

Imperviousness can be measured fairly easily and reliably, making it possible to carry out comparisons over time for one watershed, or between watersheds within a region.

In general, imperviousness is a good predictor of in-stream conditions, including physical habitat, water quality and biota (fish and benthic invertebrate communities).

Imperviousness is a very important watershed indicator from a management perspective:

- The science behind imperviousness is sufficiently well established to use imperviousness as a general measure of watershed health for planning purposes.
- Contrary to most other watershed health indicators (hydrology, water quality, biota) imperviousness is directly related to land use planning – every individual decision for a small area can be related directly to a change in imperviousness.
- Imperviousness can be used to predict the general watershed conditions in the future using population growth scenarios.
- The recent amendments to the Municipal Act allow municipalities to use imperviousness as a land use-planning tool.

7.3.3 Total versus Effective Impervious Area

The most commonly used measure of imperviousness is Total Impervious Area (TIA), which is a measure of all the areas where water no longer infiltrates into the soil. This includes all roads, sidewalks, parking areas, roofs, driveways and any other paved areas. Figure 8.1 shows an example of a residential area where these impervious areas have been delineated on an orthophoto. In this example, only the light green areas (consisting of lawn, shrubs, or forest cover) are considered pervious.

Figure 7.1 Impervious areas within one residential block delineated on an orthophoto

This definition of Total Impervious Area is incomplete from a hydrological perspective for two reasons. First, it ignores areas which are still covered by vegetation, but which have become so highly compacted or otherwise so low in permeability by urbanisation that the rate of runoff is indistinguishable from pavement. Second, it includes some paved areas that may not contribute to the stormwater runoff response of the stream channel. For example, rooftop runoff, which is not connected to a stormdrain system but is diverted into an area of green space (like a lawn or filter strip) may not contribute directly to increased surface runoff from that residential area.

The first limitation of the TIA definition is typically ignored in characterising the impacts of urban development on a watershed, and requires detailed site-level analysis. The second limitation is addressed through the concept of Effective Impervious Area (EIA), which is defined as only that fraction of the Total Imperviousness Area with a direct hydraulic connection to the downstream drainage, such as through the storm sewer drainage system. Effective Imperviousness Area is also known as Directly Connected Area (DCA). By definition, EIA is equal to or lower than TIA for the same area. EIA is considered a better predictor of the changes in stream hydrology than TIA, because it takes into account these areas which are not directly contributing. Direct measurement of EIA is complicated, and a general relationship between TIA and EIA is discussed further on in this report.

7.4 Summary Of Methodologies

A number of methodologies exist to determine imperviousness. Each of the methods will be described briefly. Figure 8.2 shows how the various methodologies relate to each other

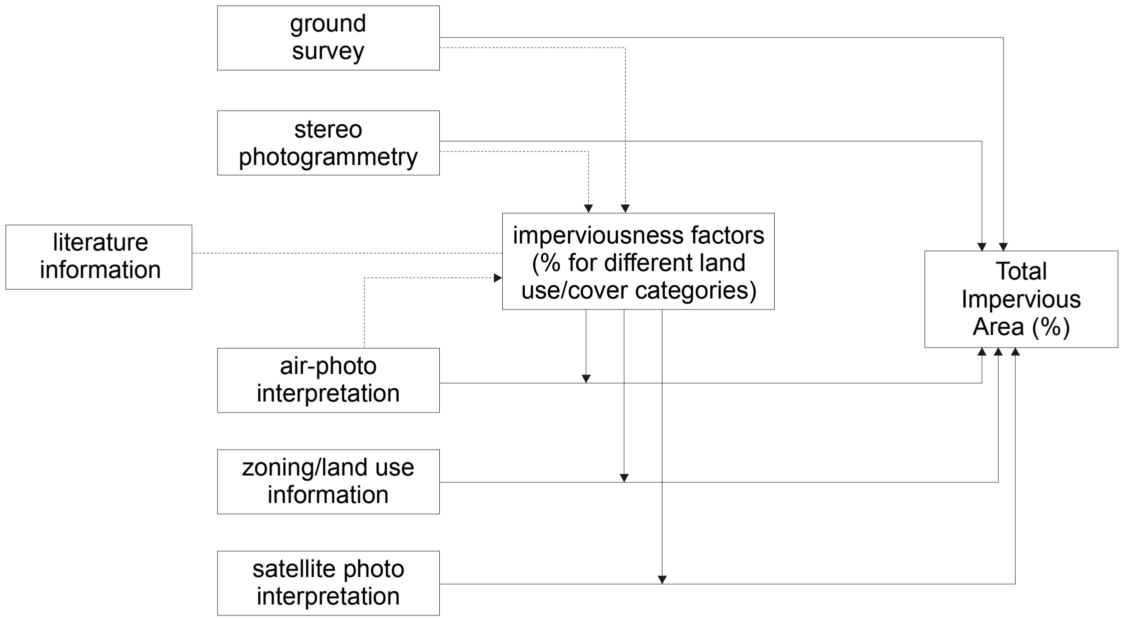


Figure 7.2 Methods to determine imperviousness.

7.4.1 Direct Measures

Direct measures include ground surveys and stereo photogrammetry. These methods are referred to as direct measures since they involve determining the outline for every impervious area, such as roads, roofs, parking areas, sidewalks etc.

Ground Surveys

Traditional ground surveys provide the most accurate method for capturing imperviousness, as they result in very accurate outlines of geographic features. Surveys are expensive and are usually only practical for the location of lot lines or for designing engineering projects; they would rarely be feasible for mapping large areas. If survey data is already available from site plans or engineering projects, it should be used. For mapping larger areas you need aerial photographs or remote sensing information.

Stereo-photogrammetry

The most accurate method for acquiring land cover information from aerial photography is with a stereoplotter. With this equipment, distortion from the camera lens, radial optics and ground terrain are removed during transfer and rectification from the original photographs.

Depending on the flight altitude and the scale of the maps, individual buildings, streets, and even sidewalks can be separated. An accuracy of less than 1 meter is typically achievable. Although it is a practical method for creating maps, the process is time consuming, requires a professional photogrammetrist and uses expensive equipment. Figure 8.3 shows an example of the results of stereo-photogrammetry.

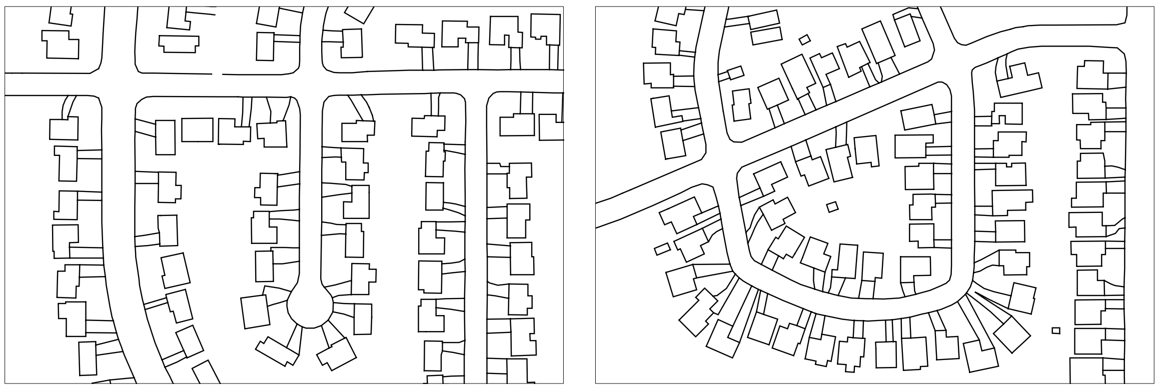


Figure 7.3 Stereo-photogrammetry examples.

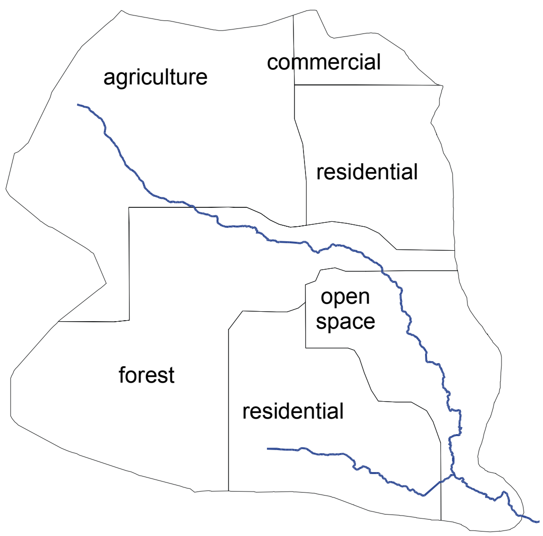
While existing data of this type is not so common, some municipalities have already invested in this type of information when creating maps for city planning. Depending on the quality of the data, imperviousness information can be derived from this information. A common limitation is that outlines are often saved as line data and not as polygons.

Depending on the quality of the ground surveys or the stereo-photogrammetry, some assumptions may be required to yield precise answers. In some analyses, areas such as sidewalks and driveways are not included since they are too small or too difficult to distinguish. Sidewalks, for example, may only appear as lines in the GIS system so these need to be multiplied with an average width to obtain an area. Similarly, driveways could be added by assuming a certain standard driveway area to each house. In addition, some assumptions will have to made on the imperviousness of non-paved areas. While this will often be assumed to be 0% in these direct measurement techniques, some level of imperviousness could be attributed to various pervious surfaces (e.g. 1% to forest, 3% to grass land etc.), similar to the use of imperviousness factors in the indirect measurement techniques.

7.4.2 Indirect Measures

Indirect measures include aerial photo interpretation, zoning information analysis and satellite image interpretation. Because of the smaller scale typically used in these methods, it is difficult to outline specific impervious surfaces. As a result, these methods calculate the imperviousness of an area by determining the land cover and/or land use category for each area which is then multiplied with the typical imperviousness of that category. Figure 8.4 shows an example of such a calculation, which involves three steps:

- creating a land use/cover map (using one of the three methods described below);
- calculating the amount of each land use/cover within the study area; and
- multiplying each land use/cover category with an imperviousness factor, typical for each category (discussed in more detail below).



Land use / cover category	% of total area	imperviousness factor (%)
forest	28	0
open space	14	5
agricultural	28	5
residential	27	30
commercial	3	80

Total Impervious Area = 12.9%

Figure 7.4 Typical imperviousness calculation using land use/cover maps

Air Photo Interpretation

In this approach data from existing aerial photographs are transferred to a rectified base-map. Manually transferring data from photographs to maps is labour intensive and is less precise than stereo-photogrammetry, but is a very practical alternative. Air photos also have the advantage that they can be used for many other purposes than determining imperviousness. With this methods it is relatively easy to create maps for small areas. Land use and land cover can be interpreted from the air photos and additional information from zoning information and/or ground surveys. The availability of orthophotos (which are already rectified) in digital format has made the use of aerial photography even more attractive, as the process of digitizing land use and cover information can be carried out much more cost-effectively.

Zoning Information Analysis

Using zoning information can be a very fast and inexpensive way to determine a rough estimate of imperviousness. Zoning information is typically already available in digital form. Zoning maps will have to be checked with aerial photographs and/or field surveys to confirm their accuracy. The use of a combination of zoning information and air photos is the most common method for measuring imperviousness in urban areas at the watershed level.

Satellite Image Interpretation

Analysis of satellite images can provides land cover and/or land use maps. Two general approaches are commonly used. The first approach is visual interpretation of the image to determine land use and/or cover, in much the same way as aerial photographs are used. The second approach is automatic classification using the spectral information in the image to determine land cover only. Control over the classification can be achieved by using test or “training” areas where the ground cover is was verified in the field. The spatial resolution of satellite imagery is typically much lower than aerial photography; 1 pixel is roughly equivalent to an area of 10x10 meters for SPOT images and 30x30 meters for LANDSAT images, while for recent orthophotos 1 pixel corresponds to area of 1x1 meter. The spectral resolution of satellite imagery, however, is typically much higher than aerial photography, as the colour or black and white image captured through photography is only a small portion of the spectrum captured through satellite imagery. This makes satellite imagery particularly well suited for identifying different vegetation types, which can be hard to interpret on air photos.

7.4.3 Surrogate Measures

Many other variables correlate quite strongly with imperviousness, including road density and population density. Often this type of data is already available in some (digital) form and can provide a quick and rough estimate of imperviousness. Relationships can be found in various guidebooks, but ideally a relationship is developed for the study region, as there is likely to be significant variation among regions.

Road Density

Road density has shown a very strong relation with imperviousness. When using road density as a surrogate measure, the following should be kept in mind:

- at very low levels of imperviousness, road density does not tend to go towards zero: even at very low levels of urbanisation there is often a fairly extensive road network, connecting farms or small urban areas on the urban/rural fringe.
- road density is a poor predictor of increases in imperviousness because densification of moderately urbanised areas results in very minor additions to the road network.

Based on these observations, road density should be considered an interim measurement, before a more thorough analysis can be completed. There are other benefits of including the road network in a watershed analysis, such as the evaluation of road crossings and fragmentation of terrestrial habitat.

Population Density

Population has also shown a very strong relation with imperviousness. Population as a surrogate measure can be useful for regional or national comparisons. When using population density as a surrogate measure, the following should be kept in mind:

- population density is typically based on census information; census area boundaries do not coincide with watershed boundaries, and the accuracy of population density estimates will depend on the size and distribution of the census areas and the sub-watershed being considered.
- population is only a good measure in areas with a relatively homogeneous pattern of urbanisation (e.g. heavy concentrations of industrial development have high imperviousness but low population density); as a result, population is most useful at a somewhat larger, regional scale for rough comparisons.
- population can be a good predictor or relative changes in imperviousness: high growth areas are likely to increase in imperviousness; while population density can be used to estimate imperviousness for a watershed, based on relationships developed elsewhere, population techniques are most useful to project future imperviousness from current conditions.

7.5 Recommended Methodology

Based on a comparative analysis of the various methodologies and the needs and capabilities of the intended audience, this manual recommends the use of a methodology with the following elements:

- A scale of approximately 1:5,000.
- Use of orthophotos as imagery (4-meter pixel or better, colour or black and white).
- Combined land use and land cover mapping.
- Use of standard imperviousness factors (local test areas where feasible).
- Use of photogrammetry where already available.

A Few Notes on Scale

The first consideration in defining a scale for imperviousness mapping is identifying the maximum and minimum size of areas to be considered. Imperviousness is most meaningful as an indicator of watershed health for relatively small watersheds, up to 4th order streams or approximately 25 km^2. This implies that imperviousness should be based on land use and land cover maps no smaller than 1:20,000. Imperviousness remains meaningful as a measure of the impact of urban development on the landscape at the site-level (e.g. a residential subdivision), and could therefore be based on land use and land cover maps of 1:2,000.

A second consideration in defining scale is a consideration of the possible uses of the imperviousness information. Imperviousness can be a very powerful indicator because it can be used to link individual site-level land use decisions to the health of the watershed in a relatively simple manner. To facilitate the use of the information, imperviousness mapping should be compatible with municipal land use planning processes and stormwater management. Ideally, therefore, land use and land cover information should be obtained at a scale of around 1:5,000.

7.6 Requirements

7.6.1 Imagery and Existing Watershed Information

Orthophoto Imagery

Colour is preferred but black and white imagery can also be used; resolution should be 4-meter pixels or better. In the absence of ortho-photos, common airphotos can be used, at a scale of 1:20,000 or better. This manual does not provide any details on the use of common airphotos, although the general approach is essentially the same.

Watershed Boundary

A watershed boundary is of course required to determine imperviousness for a watershed. This watershed boundary should be of sufficient accuracy to be useful at the scale on which land use and cover are being mapped (approximately 1:5,000). Many existing watershed boundaries (for example the BC Watershed Atlas) are not sufficiently accurate for this purpose and will normally not even have the individual (sub)watershed delineated. If no appropriate watershed boundary is already available, it has to be determined using topography information and the storm sewer drainage system.

7.6.2 Additional Information

The following information is not required to determine imperviousness, but can be very useful and should be considered.

Base-map

When using a good orthophoto, this becomes the de-facto base-map, and no other base-map is required. It is useful, however, to start from an existing base-map (e.g. municipal or TRIM), as this will have many features of use in the process of creating a land use and cover map. Unless the imperviousness analysis is done in total isolation of any other project, it is likely that at some point the imperviousness information (including land use and cover) will be overlaid with other information, so selecting a common base is highly recommended. An ideal starting point would be the municipal (legal) base, which would include parcels, roads, zoning, topography etc.

Stereo-photogrammetry

Where stereo-photogrammetry information is available (e.g. outlines of buildings and roads), it should be used. If sufficient and recent coverage is available, this can be the only source of information for imperviousness calculations, with possibly some of the correction discussed previously for missing elements. Even if the coverage is incomplete and/or out of date for the watershed, the information should be used to determine appropriate imperviousness factors for selected land use categories (discussed in the next section).

Stream Locations

While a stream network is not required to calculate imperviousness, it serves many other purposes and can help “visualise” the watershed during the analysis. This stream network does not need to be very accurate (although a highly accurate stream network is useful for many other purposes).

Zoning Information

Zoning information is not required to calculate imperviousness, but can be helpful in determining the appropriate land use classification for an area (some field verification is required). If available in digital form and up-to-date, zoning information can be a very useful starting point for digitizing land use. In highly urbanised areas in particular, exiting land use often corresponds pretty close to the zoning, so there is an opportunity for saving time in the digitizing step.

GIS Equipment and Technical Skills

While in theory imperviousness can be determined without GIS (by using tracing paper), this manual assumes the use of GIS. A basic desktop GIS (e.g. ArcView or MapInfo) is sufficient if it is capable of:

- background raster image display.
- on-screen digitizing.
- basic polygon creation/editing/cleanup.
- adding/creating attribute data.
- simple queries.

The skills required by the person(s) carrying out the imperviousness analysis consist of:

- General imagery interpretation.
- Use of a land use and cover classification.
- Basic digitizing skills.
- Basic GIS database cleanup, management and query skills.

This manual provides some details on orthophoto interpretation, the use of a land use and cover classification, and the type of GIS digitizing and database management activities to be carried out, but assumes the user is comfortable with the basics of GIS and the use of the software. If regular airphotos are used instead of orthophotos, additional equipment and skills are required.

7.7 Step-By-Step Description Of Method

Step 1 Organize Your Project

- Determine the scale of the mapping you are about to undertake (1:5,000 recommended).
- Obtain the required imagery and existing watershed information (ortho-photo, watershed boundary, municipal base-map, stereo-photogrammetry, stream network, zoning), as much as possible in GIS.
- Determine the time and resources required for the effort.
- Establish a quality control procedure, in particular if there are several individuals working on the project.

Step 2 Delineate the Watershed Boundary

A watershed boundary is a basic requirement for imperviousness calculations. This boundary needs to be sufficiently accurate for the 1:5,000 scale being pursued in this manual. Knowing the general outline of the watershed may be sufficient for identifying the area for which land use has to be digitized, but is not sufficient for the final calculations.

If a sufficiently accurate boundary is not available, this has to be determined using the stream network, topography and the storm sewer drainage network. Topography information with 2-meter contour intervals is preferred, but 10-meter is acceptable for moderate to steep terrain. For lowland areas, 10-meter contour intervals would have to be supplemented by additional information, for example from master drainage plans or field observation.

Topography is interpreted to obtain the preliminary watershed boundary. The storm sewer drainage network is then used to modify this boundary to reflect the actual surface and sub-surface drainage. In general, these modifications result in a much less natural boundary, and the watershed boundary in an urban area will often have straight lines and corners.

Given the relative small size of watersheds being considered and the degree of modifications to natural drainage patterns, differences in watershed boundaries can influence the imperviousness estimates. These differences can result from working at a different scale or using a different contour interval and interpretation of the storm sewer drainage network. Storm sewer maps are notoriously difficult to interpret by the untrained eye. Unless they have been transferred to GIS and mapped as a network (including connections and direction), they can easily be misinterpreted. Moreover, they are often out-of-date.

As an example, Figure 8.5 shows the watershed boundaries obtained by two different studies using the same scale (1:20,000) and the same information (TRIM contour lines and municipal drainage maps). Such differences in interpretation are not uncommon – it is therefore highly recommended to use an existing watershed boundary if it is deemed sufficiently accurate and to report the watershed boundary as part of the results of the imperviousness analysis.

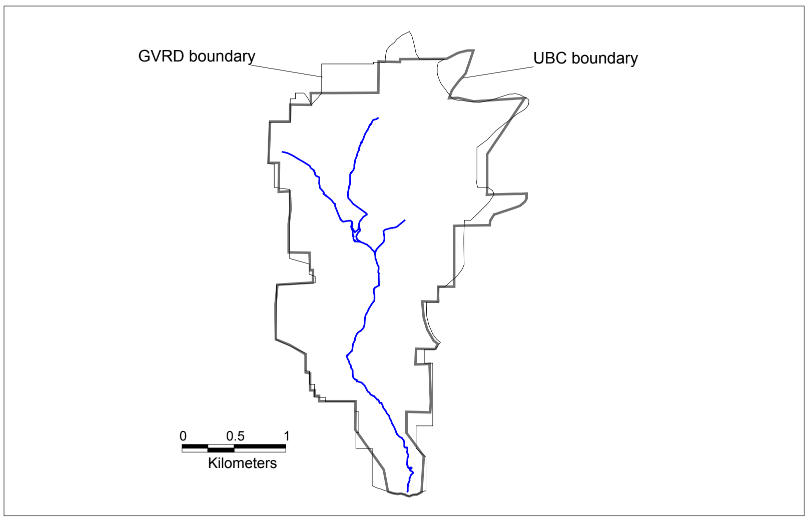


Figure 7.5 Watershed boundaries for Eagle Creek

Step 3 Map Land Use and Cover

Land Use/Cover Classifications

Land cover and land use are two related but not identical concepts: land use indicates the active land use taking place in a certain area (e.g. settlement, industrial, agricultural, recreation), while land cover indicates the vegetative, natural or artificial construction covering the land surface (e.g. forest, grass, bare surfaces, constructed areas, open water). Land use and land cover are often mapped separately, and Table 8.1 lists the general categories used for each. Depending on the level of detail of a particular mapping project, many more detailed categories are used.

Table 7.1 General land use and land cover categories

General land use categories	General land cover categories
agriculture/aquaculture	built-up areas
residential	forest (various types)
commercial	wetland
industrial	upland herbs
transportation & utilities	upland shrubs
recreation	alpine
wildlife and related activities	water
forestry	mineral
hazardous waste sites	snow and ice
water management activities	
resource protection & research activities	
energy and heat generation	
mineral and petroleum extraction	
no apparent use (open space)	

Imperviousness can be calculated using either land use or land cover maps, but the combination of land use and land cover provides the most meaningful information for a particular area. While land cover provides in theory the most accurate information for calculating imperviousness, quite frequently land cover maps do not distinguish between various types of built-up areas, which are required for imperviousness calculations. For example, a land cover map will identify all built-up areas as one category, but these will include a wide range of activities, including residential, industrial etc. Also, land cover maps do not show inclusions or individual built-up areas very well (e.g. houses, roads, and driveways within large green areas such as parks).

Therefore, land use based on zoning information and aerial photographs is most commonly used for imperviousness calculations. The main advantage of using land use information is that it describes the various types of built-up areas in great detail, which make up most of the impervious areas in a watershed. The main disadvantage of using land use information is that it identifies a number of activities which do not necessarily provide a good indication of what the actual land surface looks like (and therefore the level of imperviousness that should be attributed to them). For example, land use categories such as open space, recreation and resource protection can contain a variety of land cover types, including forest, grass, shrubs, and bare land (a substantial amount of buildings can also be found in recreation areas).

It should be noted that for most areas, land use maps are not created on a regular basis; instead they are created by a wide range of organisations with many different purposes. As a result, there is little consistency in the general approach and scale of existing land use information.

Recommended Land Use/Cover Classification

This manual recommends two possible classifications for determining imperviousness:

- Using only land use.
- Using a combination of land use and land cover.

The use of only land cover is discouraged, since it provides limited detail within the urban built-up areas. Using only land use is feasible, but somewhat incomplete. Using a combination of land use and cover will provide the most appropriate and complete information for imperviousness calculations. Table 8.2 lists the recommended land use and cover classifications for imperviousness analysis.

Table 7.2 Recommended land use and land cover categories

General land use categories	General land cover categories
agriculture	built-up areas
single family residential – low density	forest
single family residential – medium density	shrubs
single family residential – high density	grass / lawns
townhouse residential	bare / exposed soil
multifamily residential	water
commercial	
industrial	
institutional	
transportation (highways)	
utilities & special infrastructure	
recreation & parks	
forestry	
open space (no apparent use)	

In the case of ground surveys and stereo-photogrammetry, imperviousness is measured directly by summing up the roofs, roads and other paved areas. Some assumptions still need to be made regarding the level of imperviousness for other cover categories, such as grass, shrubs, forest and bare areas.

Imagery Interpretation and Database Development

Figure 8.6 shows the various steps involved in interpreting the orthophoto image and developing the GIS database required for imperviousness calculations.

- Open up the orthophoto in your GIS software – familiarize yourself with the types of features visible on the image.
- Create polygons that are uniform in use and cover.
- Give each polygon an ID number and attach the appropriate use and cover codes.

Minimum Polygon Size

There is no point in mapping really small polygons – too much effort for too little gain. Minimum polygon size and scale are closely related – at smaller scales (e.g. 1:20,000 or 1:50,000) the minimum polygon size would be much larger than at larger scales (e.g. 1:1,000 or 1:5,000). As a general guide, a scale of 1:5,000 corresponds to a minimum polygon size of approximately 0.05 ha, meaning that any area smaller than 0.05 ha will not be mapped as a unique polygon. For example, a very small area of open space (an undeveloped lot) in the middle of a residential area, will be mapped as part of that residential polygon. When mapping at a scale of 1:20,000, a minimum polygon size of 0.5 ha is more appropriate. It is very important to realize that a good orthophoto will allow for the identification of an area much smaller than 0.05 ha, but that the consistent use of the same minimum polygon size to be mapped is critical for consistency among different areas.

Uniformity of Polygons

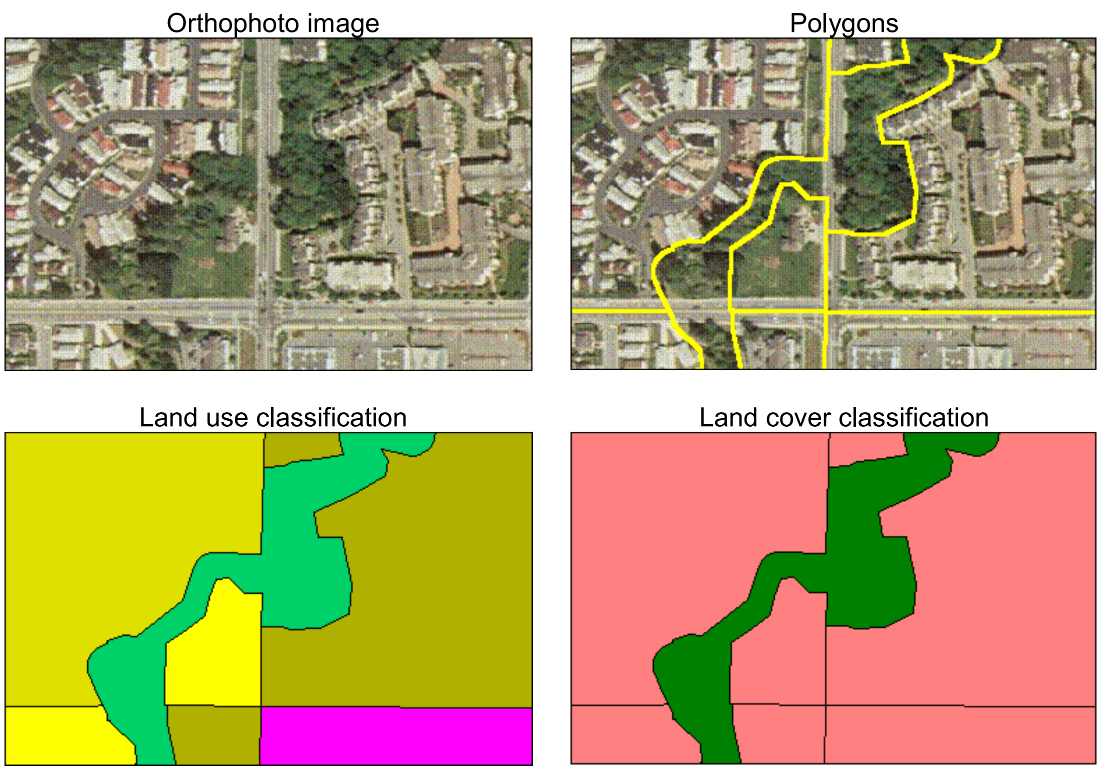
Polygons have to be created with respect to uniformity in land use and cover. For example, from a land cover perspective, residential and commercial areas are equal (built-up), but they are different in land use, so they should be mapped as separate polygons. Similarly, a forested park and a golf course are the same from a use perspective (recreation), but are different in cover (forest vs. grass), so they should be mapped as separate polygons. Figure 8.7 provides a few examples of these classifications.

Field Verification

In the early stages or leaning how to interpret orthophoto imagery, it is useful to make a printout of some sections, and see what they look like in the field. After some initial field verifications, very little fieldwork is typically required, since a good orthophoto provides a lot of detail. Some field verification may be required for unusual features.

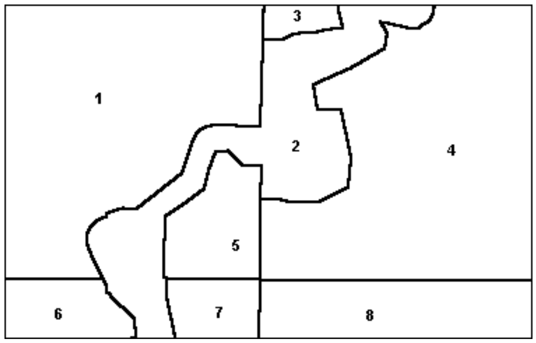
Use of Zoning Information

To assist in determining land use, a zoning map can be very useful. Zoning information is often used to determine the density of residential areas and distinguish between very similar land uses, such as commercial, industrial and institutional. If zoning information is available in digital format and is up-to-date, it could be used as the basis for the land use/cover map (i.e. the actual polygons of the zoning map could be used). However, each boundary has to be verified visually, and each polygon has to be checked for land use and land cover. Many zoning polygons will have to be broken up to accurately reflect the actual use and cover. The use of the digital zoning map is most useful in highly developed areas, where actual land use and zoning are pretty close – in other areas, it may be more effective to start creating polygons from scratch.



Polygons with ID numbers

Database



ID	Land_use	Land_cover
1	multi-family low density	built-up
2	open space	forest
3	multi-family high density	built-up
4	multi-family high density	built-up
5	single family residential	built-up
6	multi-family low density	built-up
7	multi-family high density	built-up
8	commercial	built-up

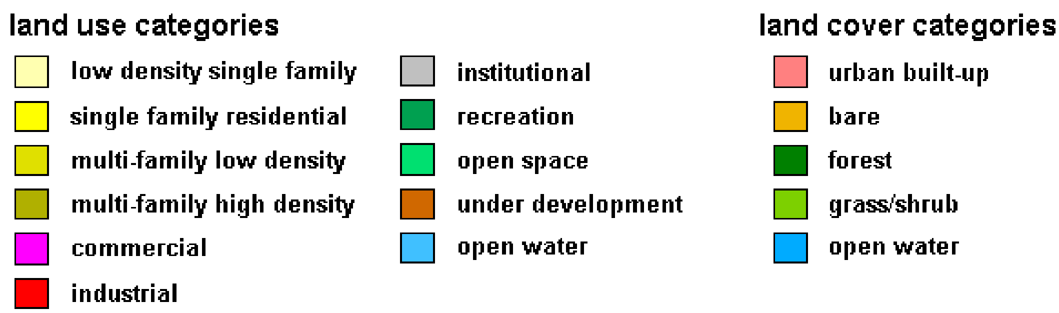


Figure 7.6 Example of imagery interpretation

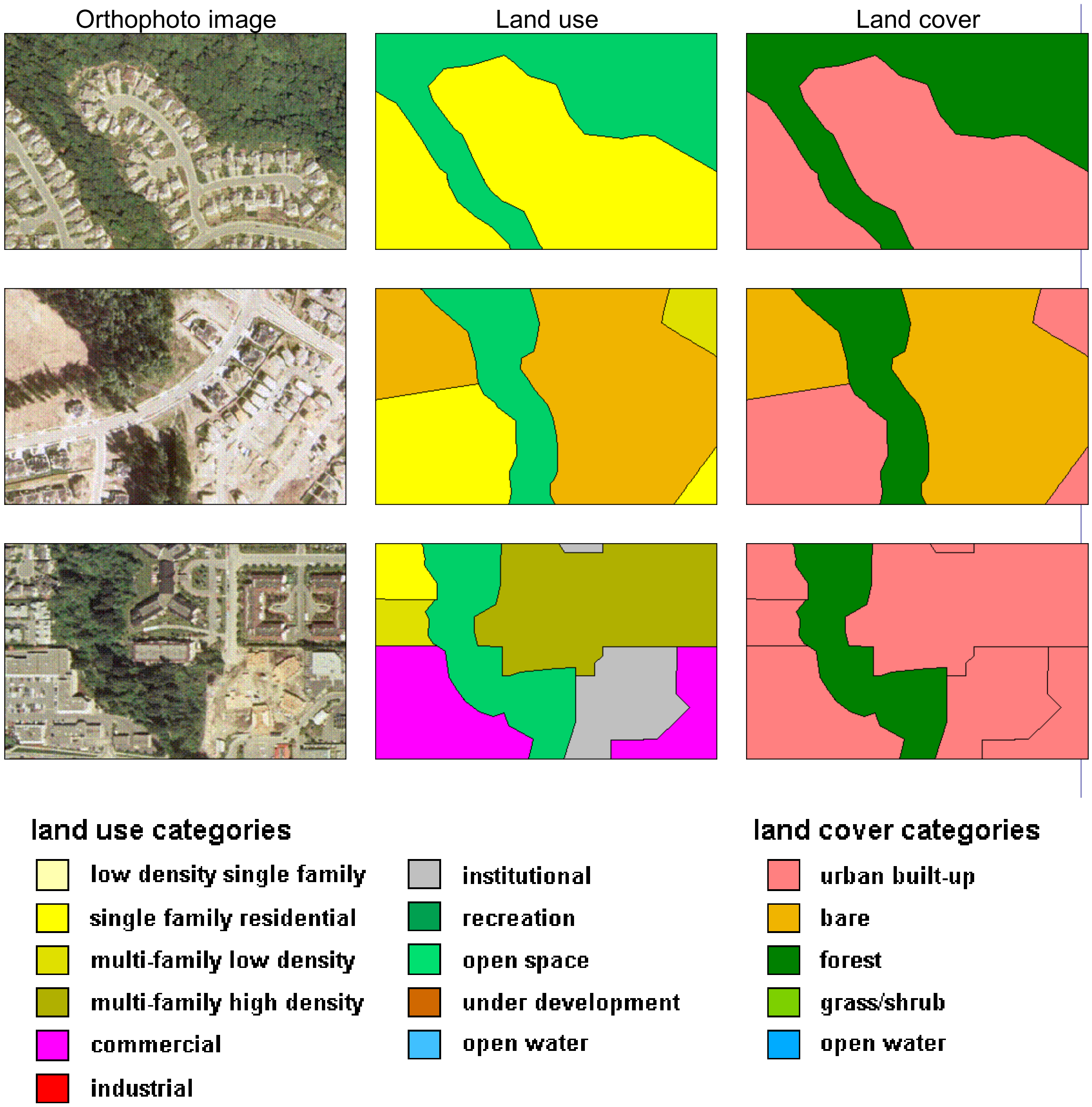


Figure 7.7 Example of land use versus cover.

Step 4 Determine Imperviousness Factors

Sources of Information for Imperviousness Factors

Determining imperviousness on the basis of land use and/or cover maps requires the use of imperviousness factors to calculate the imperviousness for a watershed. Imperviousness factors can be derived through various means:

- **open literature**: % values are provided in several guidebooks.

- **stereo-photogrammetry**: even if this type data is not available for the entire study area, it can provide accurate estimates for imperviousness factors for a specific region.
- **ground survey**: as with stereo-photogrammetry, it is rare to have this information available for large areas, but smaller areas can provide accurate estimates for imperviousness factors.
- **air photo interpretation of test areas, using a higher level of detail than used in the land cover/use mapping**: this essentially involves a manual approach to determining the outlines of buildings, roads and other paved areas, similar to what stereo-photogrammetry does automatically for large areas; if the scale of the air-photos is sufficiently large, this method can give quite accurate results.

Recommended imperviousness factors

Existing studies vary greatly in the imperviousness factors used, which limit the ability to compare results from different areas. Selecting imperviousness factors is not an easy task and should be given proper attention. A set of "typical" imperviousness factors is presented in Table 8.3.

Table 7.3 Recommended imperviousness factors.

code	Land use	imperviousness
A000	Agriculture	3%
S110	Single family	n/a[1]
S120	Suburban	12%
S130	Townhouse	65%
S135	Multifamily	65%
S200	Commercial	80%
S300	Industrial	80%
S400	Institutional	80%
S500	Transport	90%
R100	Recreation	3%
U100	Open space	3%
F100	Forestry	1%
W000	Water	0%
	Land cover	
	Forest	1%
	clear-cut	3%
	grass	3%
	shrub	3%
	bare	3%

1 No typical imperviousness factor is assigned to single family residential as this value varies greatly with housing density – details discussed further below.

One of the most difficult land use categories for which to establish imperviousness factors is single-family residential areas, for which imperviousness can vary from 20 to 65% depending on the type of housing, the overall housing density, and the design of the road network. For this reason, no “typical” value is given in Table 8.3. Instead, overall housing density should be used as a guide to selecting the imperviousness for this category. This can be done using zoning and cadastral information and/or aerial photographs. Given the often large contribution residential areas make to the total urbanised area of a watershed, establishing an appropriate imperviousness factor for residential areas is critical to the accuracy for the imperviousness calculations.

Developing Test Areas

An alternative to using only density as a guide, the use of test areas is a common way in to determine appropriate imperviousness factors. In this approach, small residential areas (a few blocks or between 3 and 10 hectares in size) are mapped in great detail, including rooftops, driveways, sidewalks, parking areas, roads and other paved areas. This can be achieved using ground surveys, stereo-photogrammetry or air photos. This level of detail is often not feasible for large areas, but can be carried out for test areas to determine appropriate imperviousness factors for a specific area. While it is feasible to do this for all types of land uses, the variability among different areas for most land uses is often not substantial enough to warrant the effort. Given the variability for single family residential areas, the accuracy of the imperviousness estimate for a watershed is likely to improve substantially when using test areas.

Example of Test Areas

As an example, Figure 8.8 shows the imperviousness factors developed by UBC (1999) for three watersheds in the Lower Mainland based on test areas using 1995 1-meter pixel orthophotos. These values for residential areas in the Salmon River, Brunette River and Hoy Creek watershed correspond fairly closely to the values reported in the frequently used USDA urban hydrology manual (USDA, 1975), lending support to the use of density as an alternative to test areas (which can be labour intensive).

However, depending on the design of the area (road network, road width, parking spaces, layout of lots, house sizes), certain regions may deviate from this general pattern.

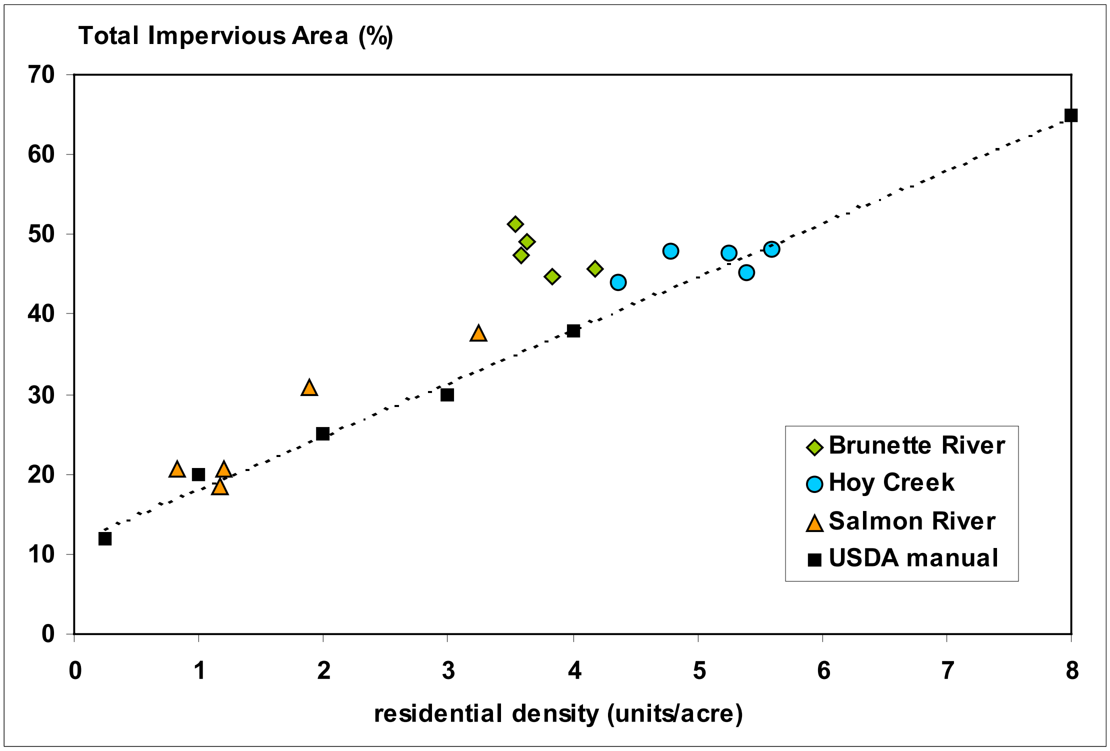


Figure 7.8 Single family residential factors (linear regression corresponds to USDA datapoints)

Step 5 Carry Out Calculations

Basics of Imperviousness Calculation

Simply put, imperviousness factors for different land use and/or land cover categories are multiplied with the areas for each of these categories within a watershed and summed up to obtain the overall imperviousness (as illustrated in Figure 8.9). This procedure is the same for any general land use or land cover map, irrespective of the source of the information.

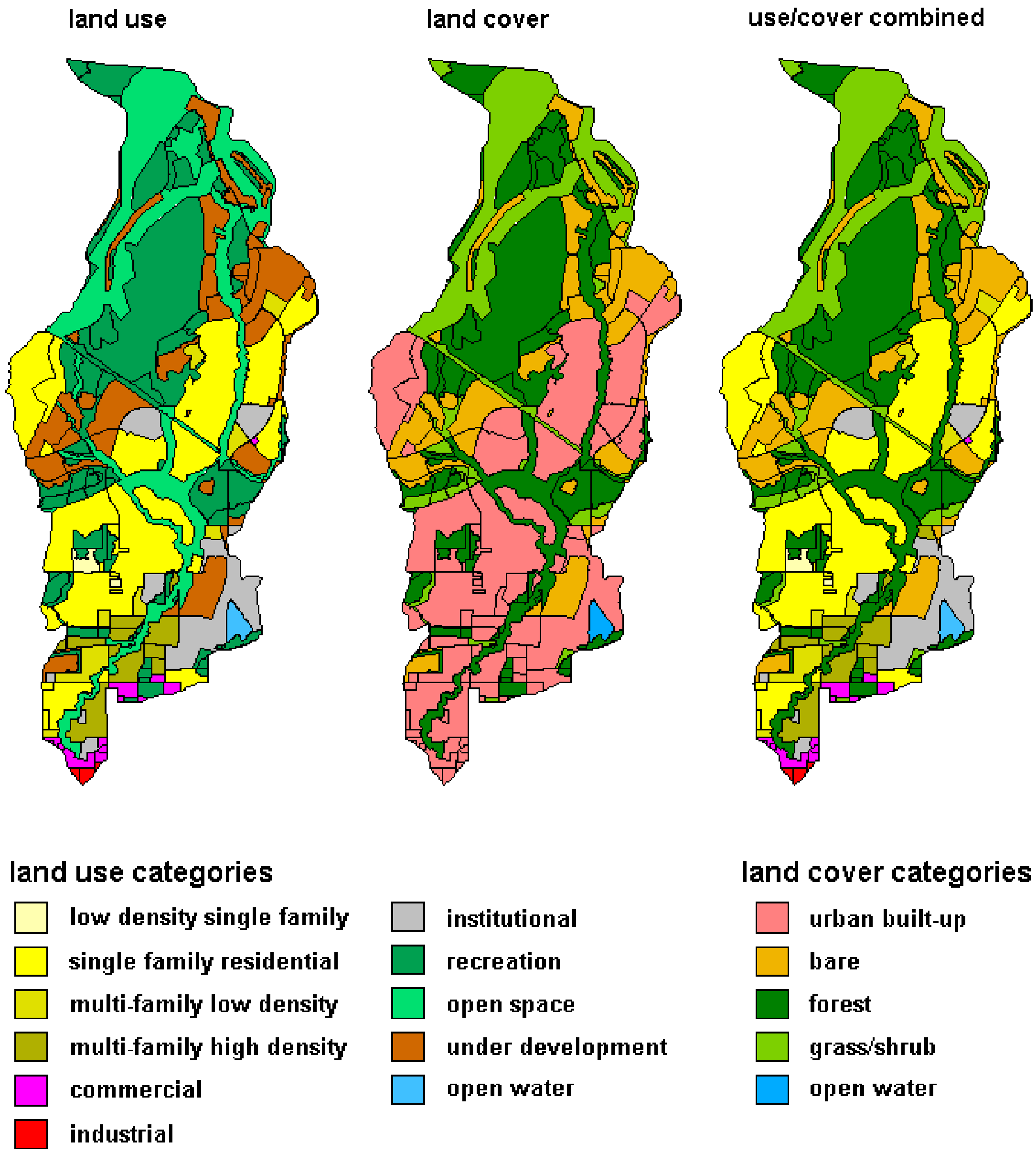


Figure 7.9 Land use map of Hoy Creek.

Table 7.4 Land use and cover for Hoy Creek (km^2).

code	description	TIA (%)	use	cover	use/cover
S110	single family	47%	1.712	-	1.712
S120	suburban	12%	0.028	-	0.028
S130	townhouse	65%	0.161	-	0.161
S135	multifamily	65%	0.259	-	0.259
S200	commercial	80%	0.082	-	0.082
S300	industrial	80%	0.016	-	0.016
S400	institutional	80%	0.409	-	0.409
R100	recreation	3%	1.407	-	-
U100	open	3%	1.758	-	-
D000	under development	3%	1.079	-	-
W000	open water	0%	0.035	-	-
U	urban	n/a	-	2.667	-
B	bare	3%	-	1.079	1.079
F	forest	1%	-	2.147	2.147
G	grass/shrubs	3%	-	1.017	1.017
W	water	0%	-	0.035	0.035
total area			6.945	6.945	6.945
TIA			23.3%		22.61%

Effective Impervious Area

As mentioned in the introduction, a distinction is made between Total Impervious Area (TIA) and Effective Impervious Area (EIA). The approach described so far only addresses TIA. One approach to measuring EIA is the use of general conversion formulas. Field research has been done on the relationship between TIA and EIA. Alley and Veenhuis (1983) developed a relationship based on a number of drainages in the Denver area: $EIA = 0.15 * TIA^{1.41}$. The formula suggests that at low levels of TIA, the EIA value is substantially lower (less than half). This makes sense intuitively, since in low density areas there are many possibilities for roof and road runoff to infiltrate into pervious areas. At high levels of TIA, the formula suggests there is almost no difference between TIA and EIA. Again, this makes sense, because for high developed areas, there will be very limited infiltration, whether or not the imperviousness surfaces are directly connected or not. Examples of estimates for EIA based on this formula are shown in Table 8.5 – these estimates may not be very appropriate for all areas.

Table 7.5 Example of EIA estimates.

land use	TIA (%)	EIA (%)
low density single family residential	10	4
medium density single family residential	20	10

high density single family residential	35	23
multifamily	60	48
commercial/industrial	90	86

7.8 Final Observations

Limitations of Imperviousness

While imperviousness is probably the single most important indicator to describe the general conditions of an urban watershed, there are a number of limitations. Some of the key limitations to consider are that:

- Imperviousness does not consider the influence of riparian buffer zones.
- Imperviousness does not reflect the potential benefits from various stormwater BMPs.
- Imperviousness does not incorporate some of the unique characteristics of each watershed, including topography, soil types and surficial materials; and
- Imperviousness does not reflect the spatial distribution of the impervious areas.

Limitations of this Methodology

The methodology described in this manual is considered appropriate for determining the imperviousness of urban watersheds, but the following limitations should be kept in mind:

- There is no well-established measure for Effective Impervious Area, which is the most accurate description of the hydrological impact of creating imperviousness surfaces.
- In the absence of orthophotos, some additional equipment and techniques are required to interpret regular air photos, not covered in this manual.
- The detailed steps covered in the manual require GIS – the same level of detailed analysis cannot be achieved without GIS.
- While the procedures described will give quite accurate results, more accurate results could be obtained through complete stereo-photogrammetry for a watershed.

- The procedures assume some training in image characterisation for those carrying out the digitizing, and quality control and quality control by a supervisor.
- The land cover mapping described in the manual is not a substitute for detailed vegetation mapping, although existing vegetation cover information could be used in the land cover analysis.

7.9 Reporting

Suggested Reporting Format

When reporting results of imperviousness calculations, the report should contain:

- A brief description of the methodology.
- The scale of mapping and imagery used.
- A table with land use and cover categories considered and imperviousness factors used.
- The justification of how the imperviousness factors were selected.
- The accuracy of land use/cover mapping and minimum polygon size used.
- A diagram with the watershed boundaries and source of boundaries.

7.10 References

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