

OAK RIDGES MORAINÉ CONSERVATION PLAN

Technical Paper Series

13 - Subwatersheds - Impervious Surfaces

1 Purpose and Overview

This technical paper provides guidance to municipalities, landowners, developers and their consultants in planning, developing and implementing the provisions of Section 27 of the Oak Ridges Moraine Conservation Plan (ORMCP).

2 Related Considerations

When preparing Subwatershed Evaluations, it is suggested that the reader also review the highlighted, associated topic areas as discussed in the ORMCP, as shown in Figure 1 below.

Clean Water Act, 2006

The *Clean Water Act, 2006* was passed on October 19, 2006. Associated regulations, Director's Rules and technical modules are currently being developed. Readers of this technical paper should take note that the requirements of the *Clean Water Act, 2006* may have implications to initiatives undertaken to implement the ORMCP. Information concerning the *Clean Water Act, 2006* is available at: www.ene.gov.on.ca/en/water/.

Further Reading

Please also refer to the additional list of resources and references listed at the end of this technical paper.

Figure 1 ORMCP Topic areas and Linkages with Technical Paper 13 - Subwatersheds - Impervious Surfaces



3 Watershed Plan Requirements of the Oak Ridges Moraine Conservation Plan

The ORMCP requirements pertaining to watershed plans are as follows:

27.

- (1) *Except with respect to land in Settlement Areas, all development and site alteration with respect to land in a subwatershed are prohibited if they would cause the total percentage of the area of the subwatershed that has impervious surfaces to exceed;*

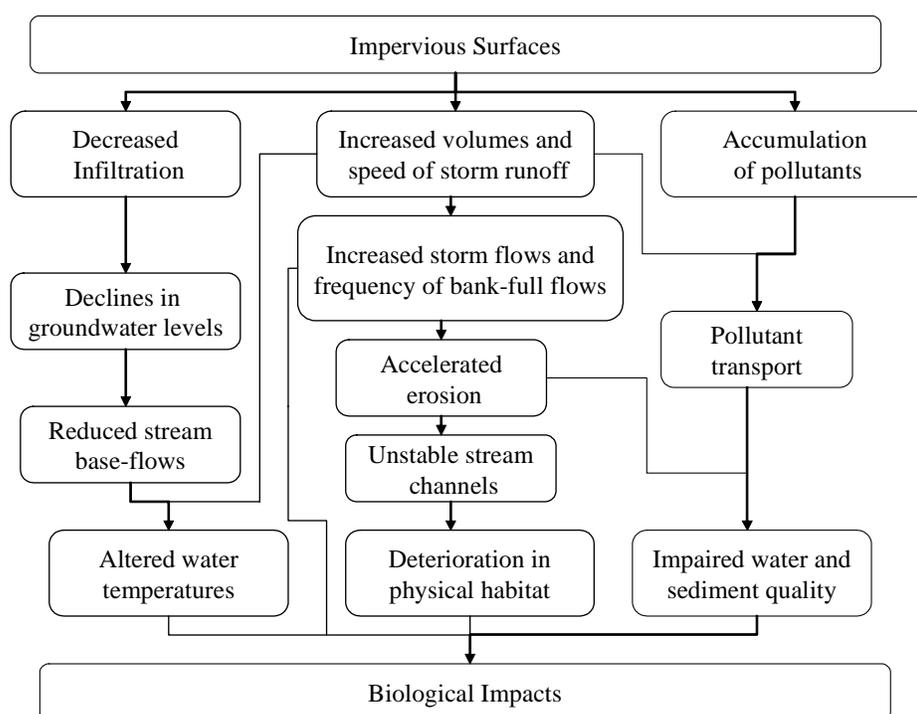
- a) 10 per cent; or
 - b) any lower percentage specified in the applicable watershed plan.
- (2) *Except with respect to land in Settlement Areas, in considering applications for development or site alteration with respect to land in a subwatershed the approval authority shall take into account the desirability of ensuring that at least 30 per cent of the area of the subwatershed has self-sustaining vegetation.*
- (3) *With respect to land in Settlement Areas, in considering applications for development or site alteration with respect to land in a subwatershed the approval authority shall consider the importance of,*
- a) *ensuring that natural vegetation is maintained, and where possible improved or restored; and*
 - b) *keeping to a minimum impervious surfaces and their impact on water quality and quantity.*

4 Rationale for the Requirements

The ORMCP defines impervious surface as a surface that does not permit the infiltration of water, such as a rooftop, sidewalk, paved roadway, driveway or parking lot. Urban landscapes are typically characterized by large areas of impervious surfaces and proportionately low levels of vegetative cover. Impervious surfaces decrease the amount of water that infiltrates into the ground, increase the volumes of stormwater runoff, and speed the delivery of runoff to streams or other receptors, resulting in a variety of environmental impacts (Figure 2). Groundwater levels and stream base-flows decline, whereas the magnitude of storm flows and the frequency of bank-full flows increase. These alterations to stream hydrology accelerate erosion, resulting in stream channel instability, and modification of the physical habitat of streams. Increased runoff and reduced stream base-flows alter stream water temperature regimes. Impervious surfaces accumulate pollutants, such as lawn fertilizers, residues from tires, and road salt, which are collected and transported by storm runoff, impacting the quality of water and sediments. Mechanisms to reduce salt loading from winter maintenance of roads and parking lots may be required to address water quality concerns with respect to infiltration of stormwater.

Cumulatively, these changes in hydrology, stream form, temperature regime, and water and sediment quality adversely impact biological communities. These changes may, for example, contribute to the local extinctions of sensitive species of fish and aquatic invertebrates from the community. Stormwater management facilities are expected to be able to reduce, but not eliminate, these impacts. For example, although it may be theoretically possible to maintain pre-development groundwater recharge rates using stormwater infiltration techniques, it may be impossible to match simultaneously pre-development to post-development water balances for both the groundwater and surface water flow systems.

Figure 2 Diagram of pathways by which impervious surfaces may impact aquatic biological communities



Because imperviousness is a direct result of urbanization, it has been proposed as a unifying theme and a general environmental indicator of change due to urban growth with implications to watershed management. Specifically, setting limits on the percentage of impervious land cover permitted within watersheds has been suggested as a potential approach to manage the effects of land development on streams in sensitive areas and to prevent cumulative impacts at the subwatershed scale. Imperviousness is one of the few variables that can be explicitly quantified, managed, and controlled at each stage of land development.

Placing a lower limit on areas of self-sustaining vegetation and an upper limit on subwatershed imperviousness are valuable conservation measures for protecting streams. There are numerous studies that demonstrate a correlation between the degree of subwatershed urbanization, as indexed by imperviousness, and the ecological condition (health) of a stream. This relationship is especially strong at the subwatershed scale for small (stream orders 1 to 3), headwater streams. The precise thresholds of self-sustaining vegetation and impervious cover necessary to conserve streams regimes are not known with certainty; however, there is a growing consensus in the literature (see Appendix A) that impairment of stream ecosystems occurs at approximately 10% imperviousness. The few studies available for watersheds of the Greater Toronto Area confirm that deterioration in the biological integrity of streams is associated with relatively low levels of watershed urbanization. The 10% threshold for impervious surfaces in the ORMCP is provided as an upper limit to be confirmed, or lowered if necessary, based on the findings of watershed plans.

5 Implementation of the Requirements

5.1 Linkages to other Activities

Figure 1 shows links between subwatershed imperviousness and other ORMCP topic areas.

The preparation of a watershed plan provides an opportunity to determine the present and projected future levels of imperviousness and self-sustaining vegetation within subwatersheds. The watershed plan may specify a target for impervious surfaces of lower than 10% within one or more subwatersheds.

Section 45 of the ORMCP requires that an application for major development be accompanied by a stormwater management plan. The stormwater management plan provides a useful context within which to consider the impervious surfaces associated with a proposed major development and techniques to minimize their impacts to water quality and quantity.

The review by the approval authority of applications for development or site alteration provides an opportunity to evaluate the implications of proposed development or site alteration with respect to the subwatershed limits to impervious surfaces and to set conditions for development approval that:

- minimize areas with impervious surfaces;
- increase areas retained in a natural undisturbed state; and
- minimize the impacts of impervious surfaces on water quality and quantity.

5.2 Determining the Present Imperviousness of a Subwatershed

The ORMCP defines a subwatershed as an area that is drained by a tributary or some defined portion of a stream. Subwatersheds will normally be defined through a watershed plan. The watershed plan technical paper recommends minimum study area units for preparing watershed plans within the Oak Ridges Moraine. Once a subwatershed's boundaries are established, the total area of the subwatershed and the component areas comprising impervious surfaces can be determined.

For the purposes of calculating the impervious fraction of a subwatershed, Settlement Areas and lands located outside of the Oak Ridges Moraine boundary may be excluded from the total area of the subwatershed (see Table 1). Nevertheless, with respect to Settlement Areas, Subsection 27(3) of the ORMCP encourages approval authorities to consider maintaining, improving or restoring natural vegetation, as well as minimizing impervious surfaces and their impacts on water quality and quantity. In addition, municipalities are encouraged to adopt a comprehensive approach to the maintenance of self-sustaining vegetation and the management of impervious surfaces throughout entire subwatersheds.

Table 1 Implementing subwatershed limits to impervious surfaces

Scenario		Implementing Limits to Impervious Surfaces
1. The subwatershed is located entirely within the ORMCP Area.	(a) No lands in the subwatershed are designated as Settlement Areas.	No development or site alteration if impervious surfaces in the subwatershed exceed 10%, or lower percentage specified in the applicable watershed plan.
	(b) All lands in the subwatershed are designated as Settlement Areas.	Impervious surfaces and their impacts to water quality and quantity are to be minimized.
	(c) The subwatershed contains both lands designated as Settlement Areas as well as lands in other ORMCP designations.	Outside of Settlement Areas, no development or site alteration if impervious surfaces calculated on the basis of the non-Settlement portion of the subwatershed exceed 10%, or lower percentage specified in the applicable watershed plan. Within Settlement Areas, impervious surfaces and their impacts to water quality and quantity are to be minimized.
2. The subwatershed includes lands within the ORMCP Area as well as lands outside of the ORMCP Area.		Compliance with the impervious surface limits to be calculated based solely on that portion of the subwatershed located within the ORMCP Area. Within the ORMCP Area, limits to be implemented as outlined in 1) above.

There are various methods for determining the existing amounts of impervious surfaces. At the site level, direct on-the-ground surveys and measurements can be made. In many cases, it may be possible to digitize or estimate impervious areas from subdivision plans, stormwater management plans, or engineering plans on file. Field surveys or aerial photographs could be used to confirm the currency of estimates derived in this manner.

Over broader areas, a Geographical Information System (GIS) can be used in conjunction with digital ortho-rectified aerial photographs for:

- random sampling
- digitizing, or
- land classification analysis.

Random Sampling is a GIS tool in which random points are generated across an image and identified as impervious or non-impervious surfaces. Provided that a sufficient density of randomly-selected points is sampled, the percent imperviousness can be estimated as the proportion of sampled points that fall on impervious areas.

Digitizing is an on-screen method to create polygons which outline impervious areas. Once the total impervious area is calculated, it is divided by the total area of the subwatershed to determine the impervious cover fraction.

Land Classification is conducted in Image Processing Software, which classifies an image based on categories of pixel values.

Table 2 provides a summary comparison of these three GIS methods. User-friendly guides to each of the methods are provided in Appendix B. The method or combination of methods to be used should be selected on a case-by-case basis. For example, random sampling could be used as a quick method for initial screening purposes, whereas a more-detailed digitizing could be used in situations where greater accuracy is required, for example, to verify information on a site-by-site basis or to resolve disputes in subwatersheds approaching the 10% imperviousness threshold. Whichever method is used, input from stakeholders or local planners may be of assistance in identifying discrepancies between the ground and maps, if the air photo coverage is incomplete or not current.

The ORMCP limits on percent imperviousness are intended to apply to the total imperviousness of a subwatershed, excluding Settlement Areas and lands located outside of the Oak Ridges Moraine Boundary. Therefore, for the purpose of evaluating compliance with the 10% limit, no distinction should be made between those impervious surfaces, such as urban roads, that are connected directly to a stormwater conveyance and those impervious surfaces, such as roofs, that may direct runoff to pervious areas such as yards.

Once the present level of subwatershed imperviousness is known, it will be important to update the information by monitoring changes to imperviousness due to land development. Depending on the extent of new development and site alteration in a subwatershed, it may also be necessary to revisit the estimates periodically, for instance, when new air photo coverage becomes available for the subject area.

Table 2 Summary and comparison of GIS methods for estimating subwatershed imperviousness

	Method		
	Random Sampling	Digitizing	Land Classification
Labour Time Required	<i>Minimal</i> , under two hours for most subwatersheds.	<i>Heavy</i> labour time requirements, up to 8 hours or more for larger subwatersheds.	<i>Intermediate</i> , 2 to 4 hours required for performing pre and post classification prep and analysis, yet little labour required during actual running of analysis.
Processing Time Required	<i>Minimal</i> , not a limiting factor.	<i>Minimal</i> , not a limiting factor.	<i>Heavy</i> demands upon computer resource, leading to potentially several hours of processing.
Computer Resources Required	Standard Desktop PC.	Standard Desktop PC.	Fast Desktop PC or workstation.
Accuracy	<i>Least accurate</i> of three methods, depends a great deal on user interpretation. Least consistent method.	<i>Potentially very accurate</i> , if analyst takes proper care and is skilled in air photo interpretation.	No possibility of analyst misinterpretation, however, <i>accuracy can vary</i> due to computer misclassification of some pixels.
User GIS Skills Required	<i>Beginner</i> GIS skills required only.	<i>Intermediate</i> GIS skills required, including ability to install and run AML scripts. As well, air-photo experience is necessary.	<i>Advanced</i> GIS and image processing knowledge required, and a high degree of technical skills.
User Friendliness	<i>Easiest</i> and least demanding method, not technically challenging.	Can be <i>tedious</i> as it demands a high level of user attention to detail.	Actual analysis requires little user input, however, image processing software is <i>complex</i> and has a high learning curve.
Computer Software Required	ArcView GIS or equivalent, with ability to display digital ortho-photos.	ArcView, ArcGIS or equivalent, with ability to display digital ortho-photos.	ArcView/ArcGIS and image processing software such as Erdas Imagine or PCI Geomatica.

5.3 Determining the Future Imperviousness of a Subwatershed

For future development, estimates of impervious areas can be obtained from subdivision plans or site plans, for either new proposals or plans approved but not yet built. In fact, estimates of imperviousness may already be provided with submissions as part of stormwater management plans or land budgets. In addition, the potential that there may be future development on existing lots should be considered. Note that some future development may be exempted from the ORMCP's requirements through the transition provisions in both the ORMCP and the *Oak Ridges Moraine Conservation Act, 2001*. The impervious surfaces from these developments should be counted as contributing to imperviousness of the subwatershed but, because of the exemptions provided, the impervious surfaces of these developments will not be subject to the subwatershed limits. Similarly, the construction of facilities for transportation,

infrastructure, and utilities uses as described in ORMCP Section 41, by a public body, is excluded from the ORMCP definitions of “development” and “site alteration” and is therefore exempted from the subwatershed limits to impervious surfaces. Although these facilities are exempt from the limits, the impervious surfaces of these facilities should still be counted as contributing to the impervious surfaces of the subwatershed.

If future impervious cover is not known, it can be estimated by the following methodology:

1. Identify undeveloped parcels by their land-use designation and zoning category in each subwatershed.
2. Subtract unbuildable land (e.g. Natural Core Areas, floodplains, steep slopes, conservation lands, etc.) from the parcel land.
3. Multiply each undeveloped parcel by an average impervious cover for the associated zoning category. The impervious cover fractions associated with various forms of existing development can be analyzed and used, in conjunction with municipal building standards, as a basis to estimate the future impervious cover fractions for various zoning categories.
4. Calculate the area of planned highways and arterial roads and add this number to the sum of the impervious area for all land uses in the subwatershed.
5. Add new impervious area to current impervious area to yield the total future impervious area.
6. Divide the total future impervious area by the total area of the subwatershed to get an impervious cover fraction, and multiply by 100 to express as an impervious percentage.

5.4 Implementing the Subwatershed Limits to Impervious Surfaces

Table 1 provides guidance on implementing the subwatershed limits to impervious surfaces.

At first glance, limiting impervious surfaces may appear to encourage development on large lots throughout a subwatershed. However, this is not the intent of the ORMCP, nor is it the best way to comply with the limits on impervious surfaces. The intent of the ORMCP is to direct and concentrate development into the Settlement Areas and away from the Natural Core, Natural Linkage, and Countryside areas. Because transportation-related imperviousness – roads, parking lots, driveways, and sidewalks – is in most cases the predominant source of imperviousness, clustered development is one of the most effective ways to reduce imperviousness. It is envisioned that the watershed plans required by the ORMCP will provide the opportunity to assess the current and projected future levels of imperviousness within subwatersheds and provide decision-makers with an estimate of how much additional development, if any, can be accommodated and where within the watershed it would be best located. Applications for new development or site alteration can be evaluated based on the implications of the additional imperviousness with respect to the 10% imperviousness limit within a subwatershed, or a lower

percentage limit specified in the applicable watershed plan. Approval authorities may choose to make available upon request information about the current and committed level of impervious surfaces within a subwatershed so that prospective developers can obtain this information at an early stage.

The Provincial Policy Statement (2005) under the *Planning Act* also provides planning guidance related to development in “countryside areas”. Section 2.3.4.3 states that “the creation of new lots in prime agricultural areas shall not be permitted, except in accordance with policy 2.3.4.1(c)” and section 2.3.5.1 specifies types of land uses that may, in certain circumstances, be permitted in prime agricultural areas.

When preparing subwatershed evaluations, it is suggested that the reader also refer to the Greater Toronto Area Agricultural Action Plan for insights into the interface between urban and agricultural land uses. The reader could also refer to documents relating to stormwater from the Toronto and Region Conservation Authority and other conservation authorities in the Oak Ridges Moraine.

5.5 Reducing Site-scale Imperviousness and its Impacts

For areas of existing or proposed new development such as in Settlement Areas, there are a number of techniques that can be used to decrease the extent of impervious surfaces or reduce their impacts. Creating pervious surfaces encourages water infiltration and minimizes the risk of flood and stormwater runoff containing harmful contaminants from reaching streams, rivers, and lakes and degrading water quality.

Options for reducing imperviousness at the site scale include clustered development, reducing or redesigning parking areas and using a hierarchy of street widths that allow for reduced widths for residential roads rather than uniform standards.

The impacts of impervious surfaces may be reduced by using best management practices, such as using porous pavement and employing techniques to reduce the direct connection of impervious surfaces to watercourses and thereby encouraging water to infiltrate at the lot-level or in stormwater conveyances. For instance, roads with grassed ditches are preferred over a curb-and-gutter design in this regard.

The Ministry of the Environment’s Stormwater Management Planning and Design Manual provides a comprehensive guide to best management practices for stormwater. The ORMCP Technical Paper 9 – Watershed Plans, provides additional information. The Center for Watershed Protection (www.cwp.org) has useful information regarding impervious cover, stormwater management, and site design.

5.6 Subwatersheds that already exceed the 10% threshold

In some cases, the initial assessment of subwatershed imperviousness may reveal that the proportion of impervious surfaces in the subwatershed is already beyond the 10% limit, or that future committed development that was approved prior to the promulgation of the ORMCP will increase imperviousness to over 10%. In these situations, no increase in imperviousness should be permitted in

those parts of the subwatershed designated as Natural Core, Natural Linkage or Countryside. As per Subsection 27(3) of the ORMCP, within Settlement Areas, consideration should be given to maintaining, improving or restoring natural vegetation and minimizing impervious surfaces and their impact on water quality and quantity. Again, watershed plans provide a context in which to consider these specific situations in detail.

5.7 Monitoring

Figure 3 shows a suggested hierarchy of monitoring related to the water provisions of the ORMCP. The scope of monitoring will vary for each program or project based on the requirements of the ORMCP, environmental targets identified in a plan, and specific conditions of an approval.

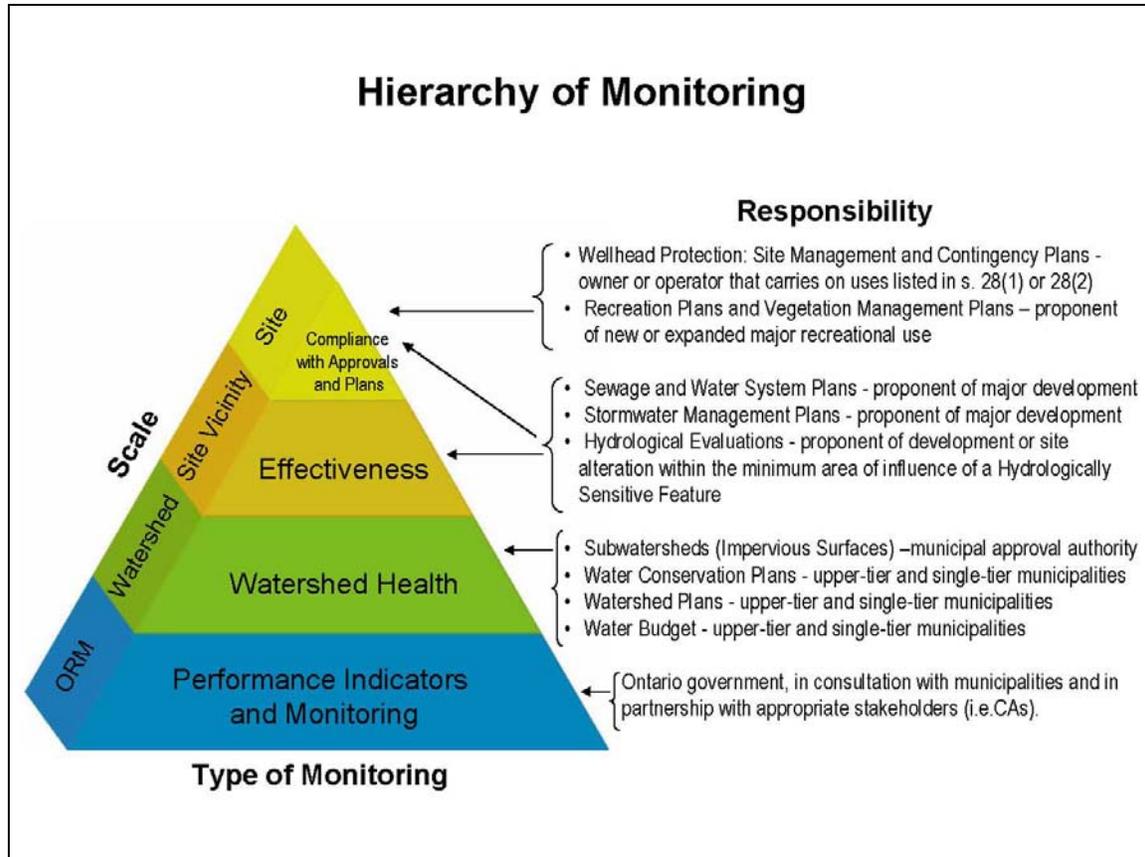
It is suggested that details of the monitoring to be undertaken, such as the frequency at which samples will be collected or observations made, the locations to be monitored, the methods to be used, and the duration of monitoring be designed to suit the specific needs of the particular program or project.

The Ontario government, in consultation with municipalities, shall over time identify performance indicators for monitoring the effectiveness of the ORMCP (see the Implementation section of the ORMCP). The Province, in partnership with appropriate stakeholders, shall establish a monitoring network to collect, summarize, and evaluate performance indicator data to:

- assess changes in the ecological integrity of the Moraine;
- assess the effectiveness of the policies of the Plan in achieving the Plan's vision and objectives;
- help identify improvements that would address problems encountered in implementing the Plan.

In addition to satisfying the needs of local watershed plans or specific projects, monitoring at the other scales (i.e. at the site, site vicinity, and watershed scales) may provide valuable information that will contribute to the overall monitoring of the ORMCP.

Figure 3 Hierarchy of monitoring related to the water provisions of the ORMCP



With respect to impervious surfaces, monitoring by the municipal approval authority is suggested:

- to track the percentages of impervious surfaces within subwatersheds to ensure that they do not exceed the 10% limit specified in the ORMCP (or lower percentage specified in the applicable watershed plan);
- to track the percentages of self-sustaining vegetation in subwatersheds to assess accordance with the target of 30% specified in the ORMCP.

To ensure that applications for development or site alteration outside of Settlement Areas are in accordance with the ORMCP, the municipal approval authority will need to evaluate whether a proposed development or site alteration can proceed without causing the subwatershed impervious surfaces to exceed the limit. Therefore, it is suggested that municipal approval authorities keep up-to-date estimates of the percentages of impervious surfaces within subwatersheds as described in this technical paper.

Upper-tier and single-tier municipalities may choose to integrate the tracking of impervious surfaces and self-sustaining vegetation into Watershed Plan monitoring, to quantify and explore relationships between the extent of land development and indicators of ecological integrity.

6 References and Resources

References

- Arnold, C. A. Jr., and C. J. Gibbons. 1996.
Impervious surface coverage - the emergence of a key environmental indicator.
Journal of the American Planning Association 62(2): 243-258.
- Center for Watershed Protection.
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- Ontario Ministry of the Environment. 2003.
Stormwater Management Planning and Design Manual. ISBN 0-7794-2969-9
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- Schueler, T and Claytor, R. 1997.
Impervious Cover as an Urban Stream Indicator and a Watershed Management Tool. In: *Effects of Watershed Development and Management on Aquatic Systems*. American Society of Civil Engineers. New York, N.Y. pp.513-529.
- Steedman, R.J. 1988.
Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 45:492-501.

List of Resources

- Center for Watershed Protection. www.cwp.org Information on watershed planning, impervious cover, restoration, research, stormwater management, site design, education and training.
- The Provincial Policy Statement (2005) under the *Planning Act*.
www.mah.gov.on.ca/
- The Greater Toronto Area Agricultural Action Plan.
www.rpco.on.ca/RPCO+GTA+Caucus/Agricultural+Action+Plan+for+GTA.htm

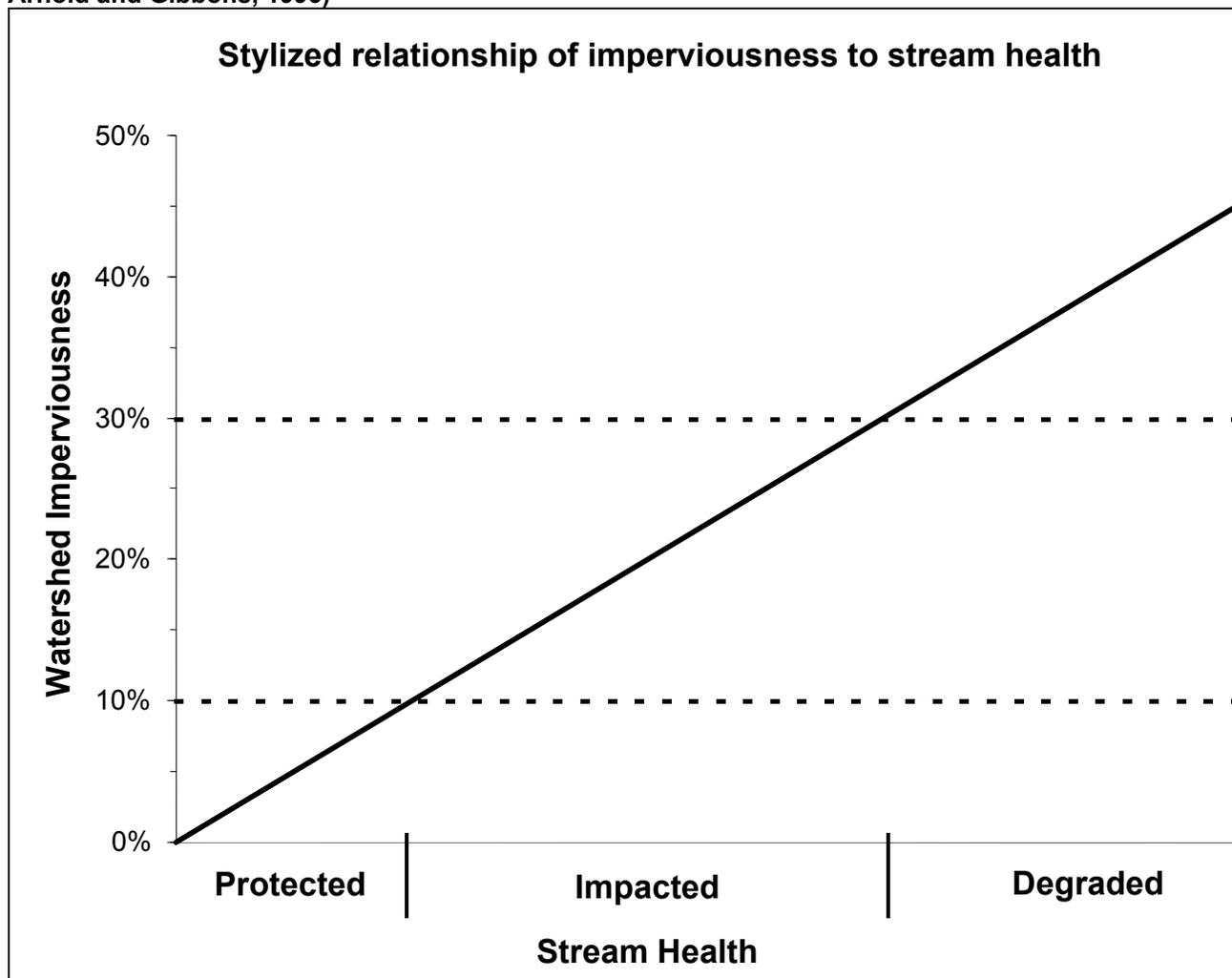
Appendix A

Imperviousness: Jurisdictional Scan

Research conducted over the past 15 years in various geographic locations has resulted in the similar conclusion that stream degradation occurs at relatively low levels of subwatershed imperviousness (6). For example, a study of 47 small watersheds in southern Wisconsin found that imperviousness between 8-12% resulted in a major drop in the number of fish species and base flow (11). A study in Washington, D.C. determined that the diversity of benthic macroinvertebrates was good to fair when imperviousness was less than 10% but diversity became poor when imperviousness exceeded 12% (7). A similar study in Delaware found that aquatic insect diversity fell into the poor category at levels of 8-15% imperviousness (8). A study of Greater Toronto Area streams used a measure of urban land use (both pervious and impervious urban areas) to determine that fish diversity changed from fair to poor when urban land constituted approximately 35% of a watershed (9). Other authors estimated that this value of urban land use corresponds to approximately 7-10% imperviousness (2). Studies in the Pacific Northwest (U.S.) reported deterioration in the physical and biological condition of streams and wetlands almost immediately in the urbanization process as total impervious area increased to 5-8% (2, 3). A study of four headwater streams in Maryland found an inverse relationship between subwatershed imperviousness and the total numbers of fish species and sensitive species. At 55% imperviousness, no sensitive fish species remained (7). In another Maryland study, a variety of hydrological, water quality, and biological information was used to conclude that serious impairment could be prevented if watershed imperviousness does not exceed 15%, or 10% for more sensitive ecosystems with self-sustaining trout populations (4).

A decision-making framework for streams in Melbourne, Australia uses an imperviousness threshold of 12% (10). Researchers from the Center for Watershed Protection in Maryland proposed an urban stream classification model based on a series of individual indicators of stream quality. The model proposes a threshold of 10% watershed impervious cover at which sensitive stream elements are lost and a second threshold around 25% to 30% impervious cover where most indicators of stream quality consistently shift to a poor condition (1). An adaptation of this model is shown in Figure A.1.

Figure A.1 Graph depicting stylized relationship of imperviousness to stream health (Modified from Arnold and Gibbons, 1996)



There are regulations governing impervious cover in a number of jurisdictions in the United States (1). For example, in Maryland, a limit of 10% imperviousness is applied to designated Special Protection Areas (5). Ordinances limiting impervious cover have also been established in Austin and San Antonio, Texas because of concerns about the quality of the area's major drinking water supply aquifer, as well as in some communities in Florida. A limit of 5% imperviousness applies to a small residential area adjacent to a coastal shellfish protection zone in Maine. The City of Olympia in Washington has a comprehensive program to reduce impervious surfaces (1).

Citations – Appendix A

- (1) Arnold, C. A. Jr., and C. J. Gibbons. 1996.
Impervious surface coverage - the emergence of a key environmental indicator. *Journal of the American Planning Association* 62(2): 243-258.
- (2) Booth, D. and L. Reinelt. 1993.
Consequences of Urbanization on Aquatic Systems – measured effects, degradation thresholds and corrective strategies. In: *Proceedings Watershed '93: A National Conference on Watershed Management*. pp. 545-550. March 21-24, 1993. Alexandria, Virginia.
- (3) Horner, R., D. Booth, A. Azous, C. May. 1997.
Watershed Determinants of Ecosystem Functioning. *Proceedings of the Engineering Foundation Conference, 1997*. ASCE: New York, NY. pp. 251-277.
- (4) Klein, R.D. 1979.
Urbanization and stream quality impairment. *American Water Resources Association*. 15(4) 948-963.
- (5) Montgomery County Department of Park and Planning, the Maryland-National Capital Park and Planning Commission. 2000.
Guidelines for Environmental Management of Development in Montgomery County.
- (6) Schueler, T. 1994.
The Importance of Imperviousness. *Watershed Protection Techniques*. 1(3): 100-111.
- (7) Schueler, T. and J. Galli. 1992.
Environmental Impacts of Stormwater ponds. In: *Watershed Restoration Source Book*. Anacostia Restoration Team. Metropolitan Washington Council of Governments. Washington, D.C., 242 pages.
- (8) Shaver, E., J. Maxted, G. Curtis, and D. Carter. 1994.
Watershed protection using an integrated approach. In: *Stormwater NPDES Related Monitoring Needs*. Engineering Foundation. American Society of Civil Engineers. Crested Butte, CO. August 7-12, 1994.
- (9) Steedman, R.J. 1988.
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- (10) Walsh, C. J., and P. F. Breen. 1999.
Urban stream rehabilitation through a decision-making framework to identify degrading processes and prioritize management actions. *Second Australian Stream Management Conference, February 8-11, 1999, Adelaide, Australia*.
- (11) Wang, L, J. Lyons, P. Kanehl. 2001.
Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management*. 28(2): 255-266.

Appendix B GIS methods for estimating subwatershed imperviousness

Random sampling method in Arc-View

1) Required Data

To begin, the user will require the following files:

- Geo-referenced Ortho-photos covering the selected region of study
- GIS boundary file (polygon) for the region of study (sub-watershed)

Impervious surfaces to be considered include:

- Houses, buildings, factories & all structures.
- Pools, arenas, tennis courts.
- Paved roads, driveways, parking lots.
- Any other human-made objects that are permanent that does not allow water to penetrate into the ground.

To generate random samples, an Arc-View extension will need to be added to Arc-view.

2) What is a random sample?

Random Sample generates a specified number of randomly placed points within a polygon. These points are then added to the view as another theme. These randomly placed points can then be used to analyze the accuracy of a digitized image or land classification. In the case of this project they are being used to determine a percentage of impermeable land in the study areas.

- To download the Arc-View extension, download the file (simplers.avx) located on the CD-Rom in a folder named "Scripts & Extensions" into the EXT32 directory. By default, this is at C:/esri/av_gis30/arcview/ext32.
- It will then appear in the extension list (found in the Project ® Extensions menu) as "Simple random sampling". Select this extension. (See Figures B 1 & B 2)
- Open the "Theme" menu and select the "Sample.." option. The random sampler dialog box will then appear
- Within the dialog box, choose the sampling strategy as "by number". (See Figure B 3). Click "Ok".
- Then the sampling utility will prompt you for the number of random points to be generated. Enter "100". Click "Ok". (see Figure B 4)

Note: The value of 100 points has been suggested based on the general practices used by image analysis professionals. For every class of landscape feature, a minimum of 50 sample points is suggested in order to create a representative sample. Since this study uses two classes (impervious and non-impervious), a minimum of 100 points is required.

Figure B 1 Select Extensions

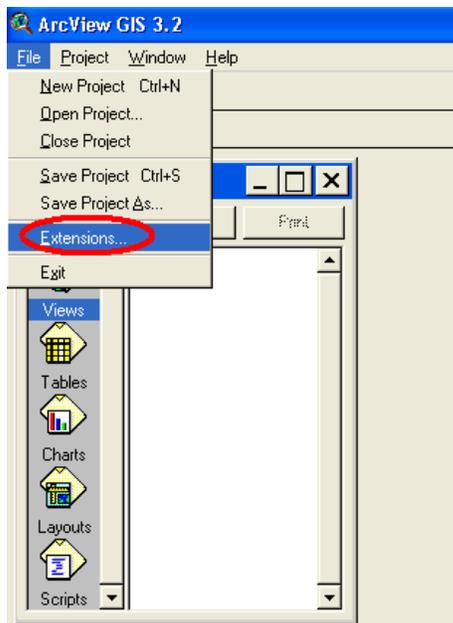


Figure B 2 Select Simple Random Sampling

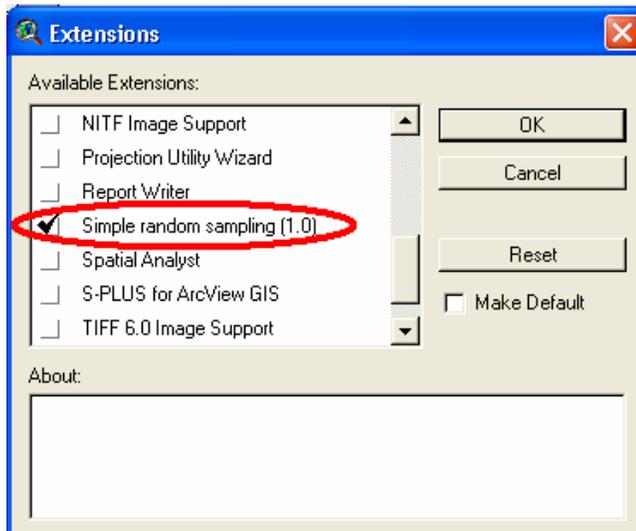


Figure B 3 Select by Number

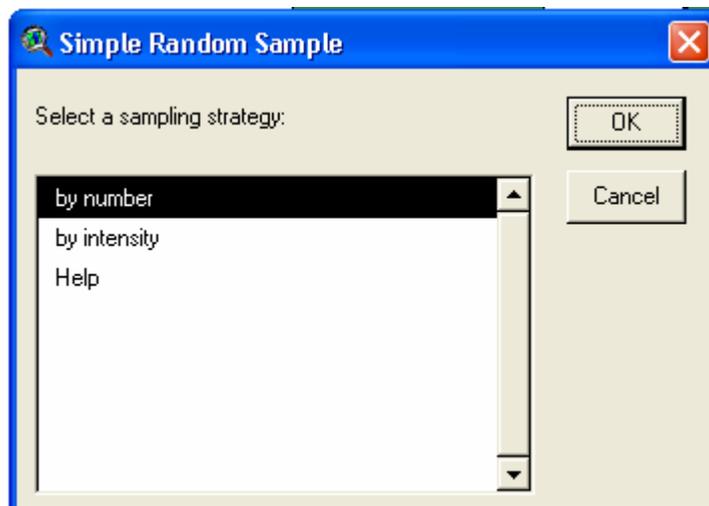
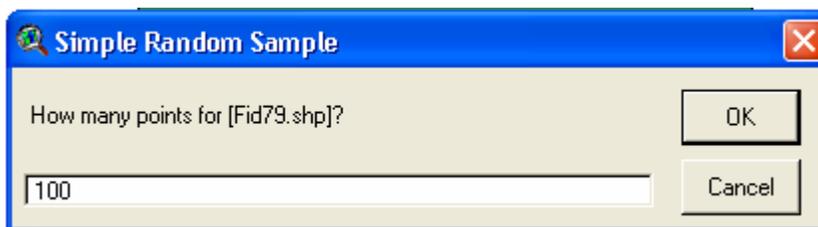


Figure B 4 Enter 100



- vi. The user will then specify the filename and location to save the random sample points theme. Once saved, ArcView will automatically add the points theme to the View. To observe a study area with random sample points see Figure B 7.

What does this specific extension do?

Simple Random Sample computes random sets of points within polygons in two ways. It can (1) choose points independently and uniformly within the selected features of a theme or (2) choose points independently within features with a sampling intensity proportional to feature area. In the first mode, "by number", you are creating a simple random sample of the union of all selected features. It is the nature of randomness that some of the features may receive no samples while others may receive far more than their "fair share." In the second mode, "by intensity", you can guarantee that each feature has approximately the "right" number of samples. (The sample points will look like a dot density map for the feature areas.)

The output is in the form of a point shapefile. The output points receive sequential identifiers only.

3) Estimating Percentage Impervious Surfaces using Randomly Generated Points

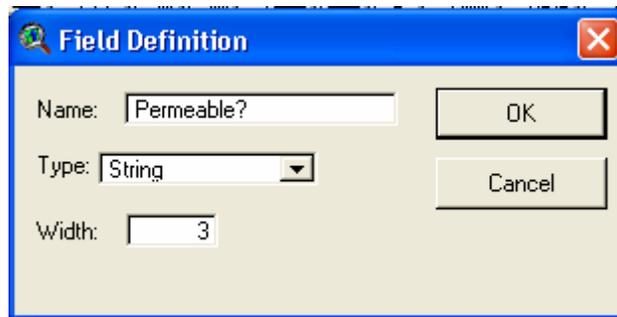
- i. Select the random points theme in the View, making it active.
- ii. Open the Attribute Table for this layer. Select "Theme @ Table". The attribute table will now be displayed.
- iii. A new column will need to be added to the attribute table. This can be accomplished by selecting the "Table" menu and choosing "Start Editing".
- iv. Access the "Edit" menu and choose "Add Field". The "Field Definition" dialog box will appear.
- v. In the "Name" field enter "Permeable?"

In the "Type" field select "String"

In the "Width" field enter "3"

Click "OK" (see Figure B 5)

Figure B 5 Field Definition

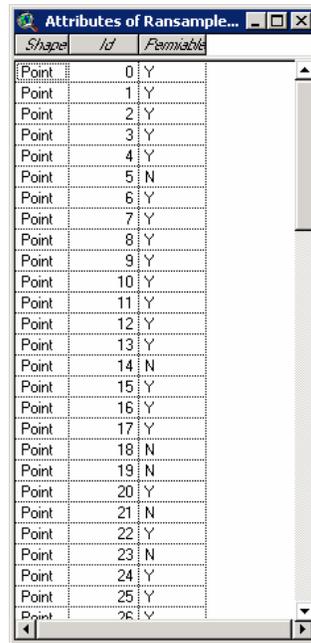


- vi. Re-open the attribute table. A new column named "Permeable?" will have appeared
- vii. The next step is then to define each of the points. They have to be defined as permeable (Y) or not permeable (N). To do this each point will have to be examined visually with an ortho photo background. Zoom in on the point until you can discern if the area where the point lies is permeable or not. For examples refer to Figures B 8 and B 9. If a point lies on a permeable surface, enter "Y" in the attribute table in the appropriate row. If the random point lies on an impermeable surface, enter "N" in the attribute table record for that point. (see Figure B 6)
- viii. Once the visual examinations are complete, the calculation of the percentage of impermeable land can be accomplished. First you must stop editing and save the edits ("Table → Stop Editing").
- ix. The total number of "N" observations needs to be tallied. The "Permeable?" column can be sorted once it has been selected in the attribute table viewer. Then the sorting process can be initiated using the "Sort Ascend" icon. 

- x. Once the sorting process has been completed, manually select all the “N” records in the table. The number of total selected records will be displayed by ArcView under the icon bar at the upper left corner of the screen. 4 of 100 selected
- xi. The final step is to divide the number of selected (“N”-“Permeable?”) by the total points (100). This results in the percentage of impermeable land in the study area based on random samples.

Note: The last number in the attribute table is “99”. This is because the table has a “0” as a record, which results in the total of 100 records (points).

Figure B 6 Attributes of random points



Shape	Id	Permeable
Point	0	Y
Point	1	Y
Point	2	Y
Point	3	Y
Point	4	Y
Point	5	N
Point	6	Y
Point	7	Y
Point	8	Y
Point	9	Y
Point	10	Y
Point	11	Y
Point	12	Y
Point	13	Y
Point	14	N
Point	15	Y
Point	16	Y
Point	17	Y
Point	18	N
Point	19	N
Point	20	Y
Point	21	N
Point	22	Y
Point	23	N
Point	24	Y
Point	25	Y
Point	26	Y

Figure B 7 Random sample points for a subwatershed polygon

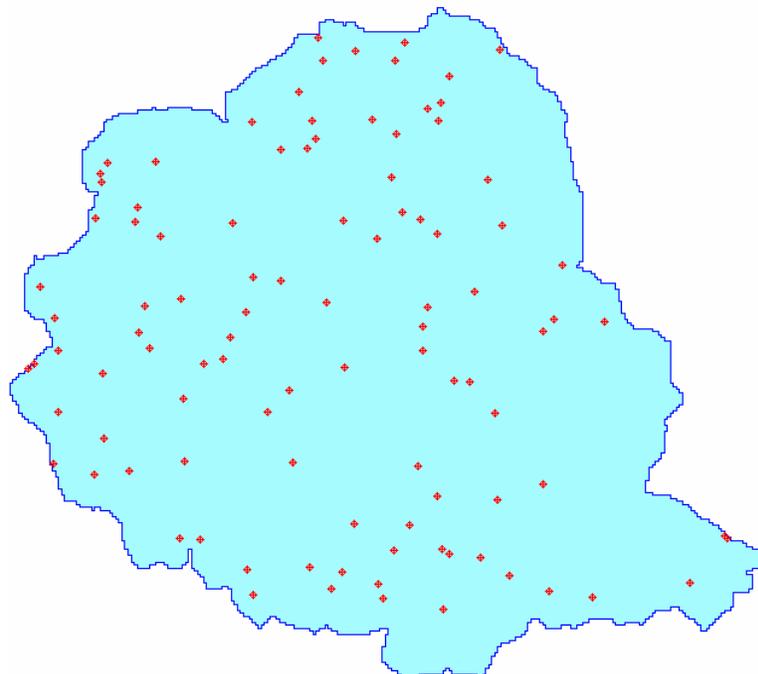


Figure B 8 Road



Figure B 9 Tennis Court



Digitizing method in Arc-View

1) Required Data

To begin, the user will require the following files:

- i. Geo-referenced ortho-photos covering the selected region of study;
- ii. GIS Road network file; and
- iii. GIS boundary file (polygon) for the region of study.

Impervious surfaces to be digitized include:

- Houses, buildings, factories & all structures;
- Pools, arenas, tennis courts;
- Paved roads, driveways, parking lots; and
- Any other human-made objects that are permanent that does not allow water to penetrate into the ground.

2) Preparing Road Dataset for Analysis

Most municipal users will have a GIS road network dataset, which already conforms to the boundaries of their study area. If this is the case, please move forward to Section #3.

For those users that will need a subset of the road dataset which conforms to their study area, a clip procedure will need to be employed in ArcView.

(a) Procedure for Clipping in ArcView GIS

- i. Ensure that both datasets (roads network and study area boundary file) are displayed in the current view;
- ii. Activate the *Geoprocessing* Extension. This can be accomplished by clicking: **File** → **Extensions** → **Check the “Geoprocessing” option** → **Select “Ok”**;
- iii. Click the **“View”** menu and select **“Geoprocessing Wizard”**.
- iv. In the **Geoprocessing Wizard** dialog box, select “Clip one theme based on another” and select “Next” (see Figure B 10);
- v. **“Select input theme to clip”**: Select the road network file (see Figure B 11);
- vi. **“Select a polygon overlay theme”**: Select the study area boundary file;
- vii. **“Specify the output file”**: Choose the name and location to save the output shapefile. Select “Finish”.
- viii. The Clip operation will then run. Upon completion, the new clipped road file will be added as a new theme to the View.

Figure B 10 Clip one theme based on another

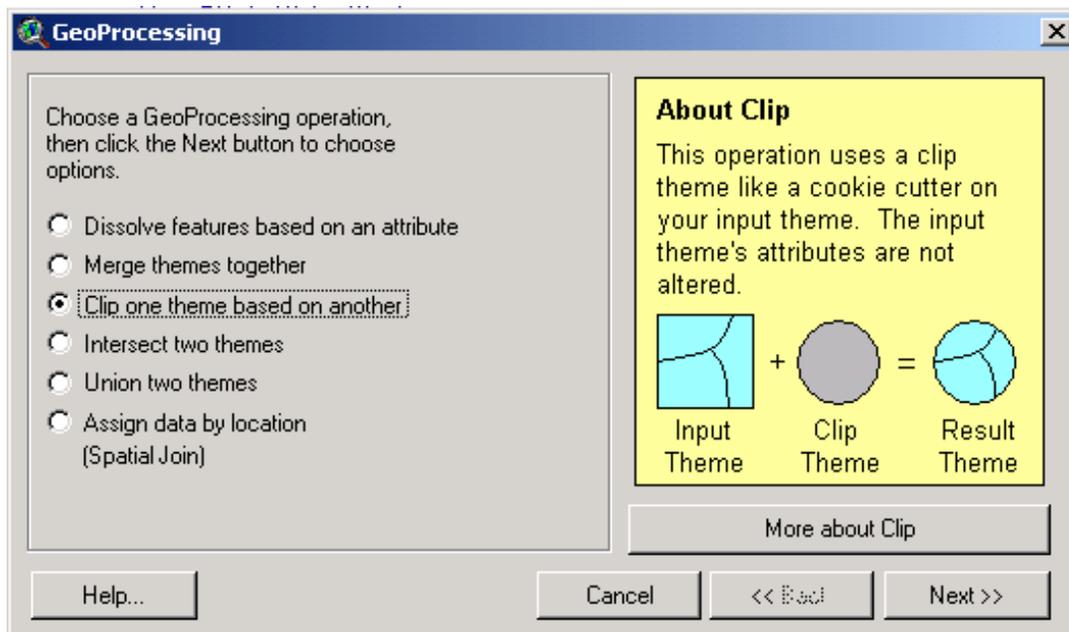
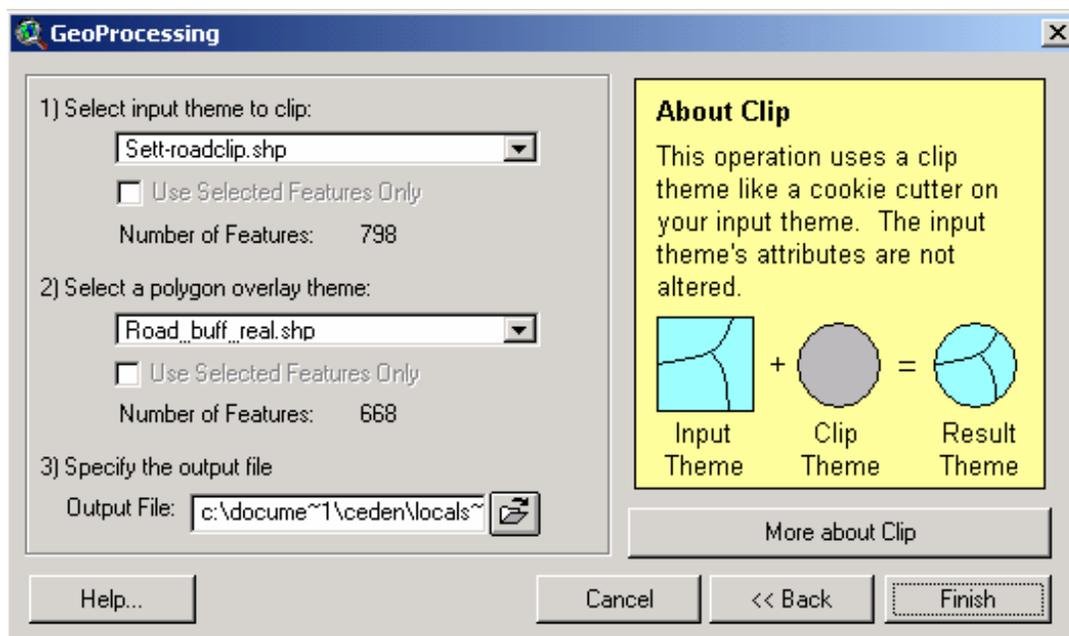


Figure B 11 Select input theme to clip, polygon overlay theme, and specify output file



3) Digitizing Roads

While roads may be digitized manually, a time and labour-saving technique involves using the GIS road network file for the region of study. Although the road data is often a line file, GIS “buffering” can be used to transform this line data into a polygon.

Note: If the user has a double line/polygonal road file, the buffering step is not necessary and the user can proceed to **Step #4**.

A buffer is a “zone of specified distance around features¹”; creating a new polygon around a feature (in this case, the road network dataset).

Before starting the ‘Buffering’ procedure, the user must decide the average width of the roads in their study area.

Note: A standard two-lane road with sidewalks is approximately 11 metres. If unknown, users can determine road width from their Ortho-photo images using the ArcView measurement tool.

- i. Click “Theme” → “Create Buffers. **Note:** If the Create Buffers menu choice is disabled, the view’s map and distance units will need to be set. (View → Properties → Select “metres” for Map Units and Distance Units → Ok;
- ii. In the “Create Buffers” Dialog Box, select “The Feature of a Theme” and then choose the road network file which conforms to the study area boundaries (the file clipped by the user in **Step #2**). Click “Next”. (see Figure B 12);
- iii. Select “At a specified distance”. Enter the desired buffer width. (see Figure B 13) Click “Next”;
- iv. When prompted to “Dissolve barriers between buffers?”, select “Yes”. Then in the “Create Buffers So They Are” submenu, choose “inside and outside polygons”. Finally, choose to save the buffer “in a new theme” in any location. Click “Finish.” (see Figure B 14).

Note: The value entered in the buffer dialog box will be *half* of the desired average road width. Example: To attain a buffered road of 11 m width, enter 5.5 m in the dialog box.

Figure B 12 Buffer the features of a theme

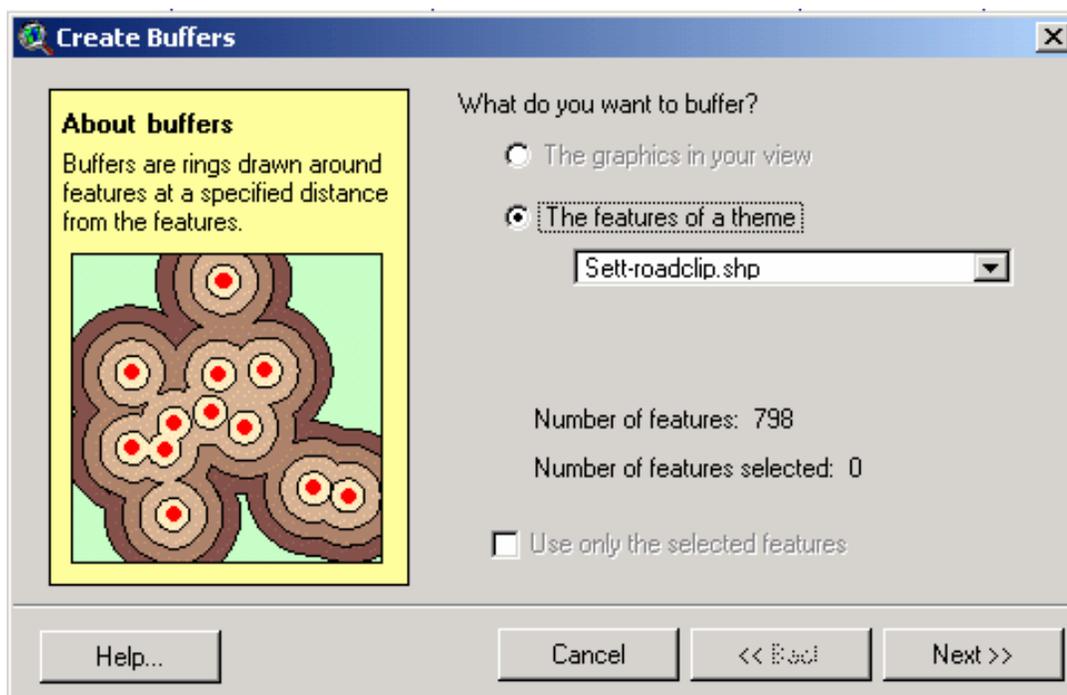


Figure B 13 Create buffers at a specified distance

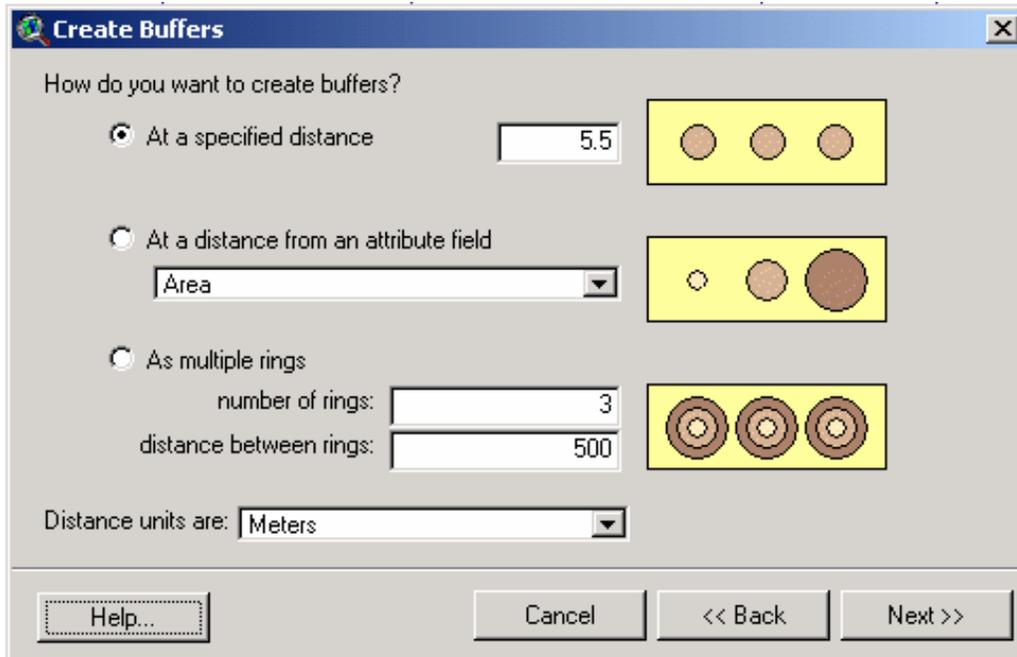
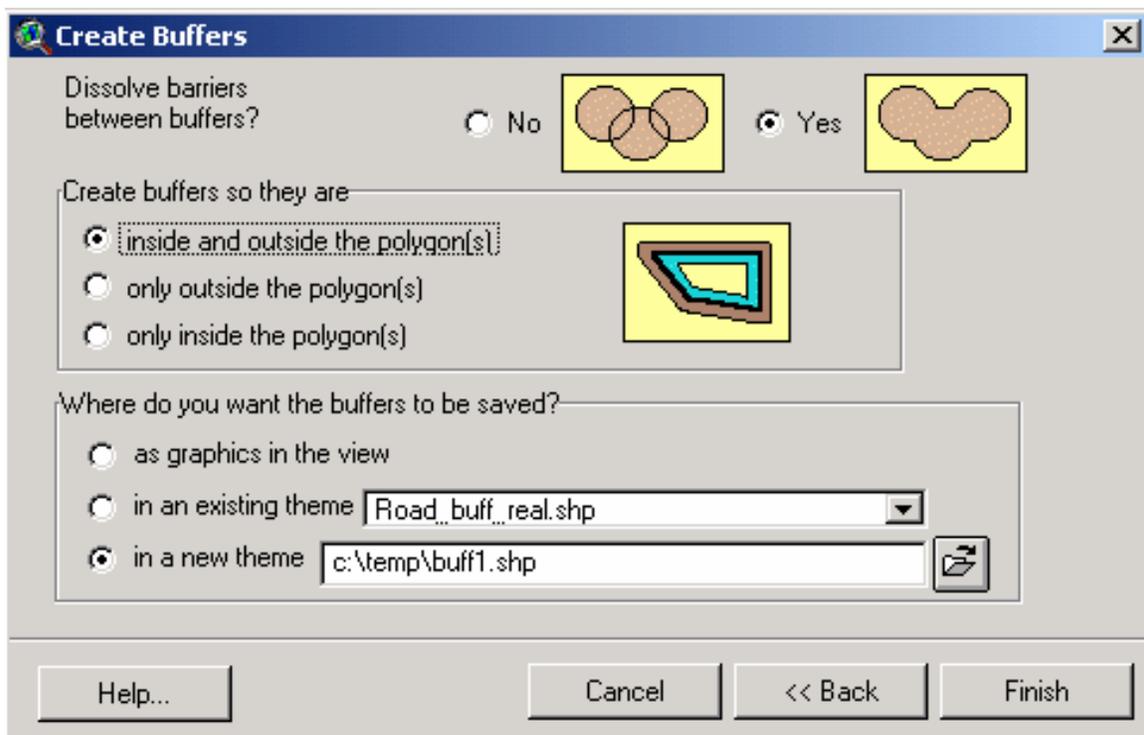


Figure B 14 Create buffers at a specified distance

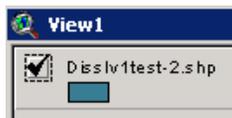


4) Digitizing Other Impervious Surfaces from the Ortho-photo Images

While digitizing the roads network can be accomplished automatically using buffering, digitizing other features can only be performed manually. This requires editing the buffered roads file.

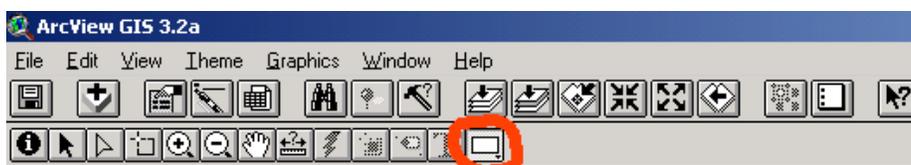
- i. The buffered roads file must be made *editable* by first activating the roads layer. Then click the “Theme” menu and select “Start Editing”. This will create a dotted box around the theme, indicating it is ready to be edited. (see Figure B 15);

Figure B 15 Start editing the theme



- ii. Select the “Draw Polygon” tool (see Figure B 16). Then begin digitizing impervious surfaces by tracing around their extent on the ortho-photo image.

Figure B 16 Select the "Draw Polygon" tool



Note: For consistency and accuracy, it is recommended when digitizing, to remain a constant scale value. A suggested scale is 1:2000 m.

- iii. For examples of the expected result of accurate on-screen digitizing, see below: Figures B 17 & B 18;

Figure B 17 Ortho-photo image before digitizing



Figure B 18 Ortho-photo image after digitizing



- iv. Once digitizing of all impermeable surfaces in the study area is complete, select “Theme” → “Stop Editing”. When prompted to “Save Edits?”, select “Yes”.

5) Calculating the Area of Impervious Surfaces in the Study Area

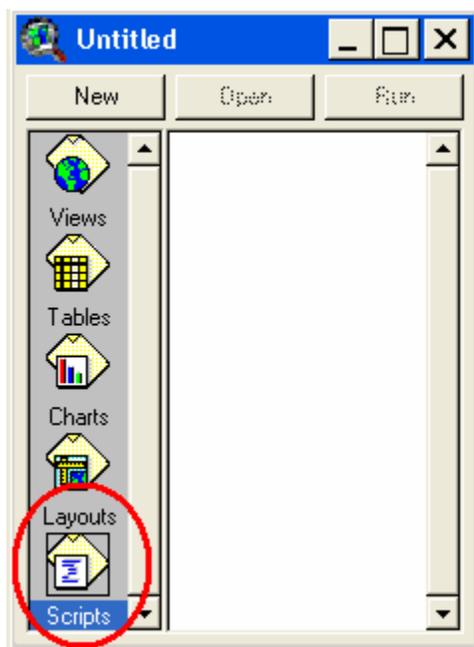
To calculate the area of the newly digitized polygons you must first download an ArcView Arcscript. This will allow the ArcView program to manually calculate the area of all of the individual polygons.

To calculate the area the user will have to add an Arcscript, which was developed by Dr. Guoyun Zhou, Kyushu University, Fukuoka city, Japan, which is available from the Esri Arcscript download page (<http://arcscripts.esri.com/>). This script has been added to the CD as (area.ave located in the folder named "Scripts & Extensions"). There is also a zipped version of the script in the folder.

6) Loading Area calculate tool ArcScript in ArcView

- i. Go to the Project Window;
- ii. Click the Scripts icon. Double click New (to make a new scripts window)
Note if this is Script 1 or another number. That will be the script name used below. (See Figure B 19);

Figure B 19 Make a new scripts window

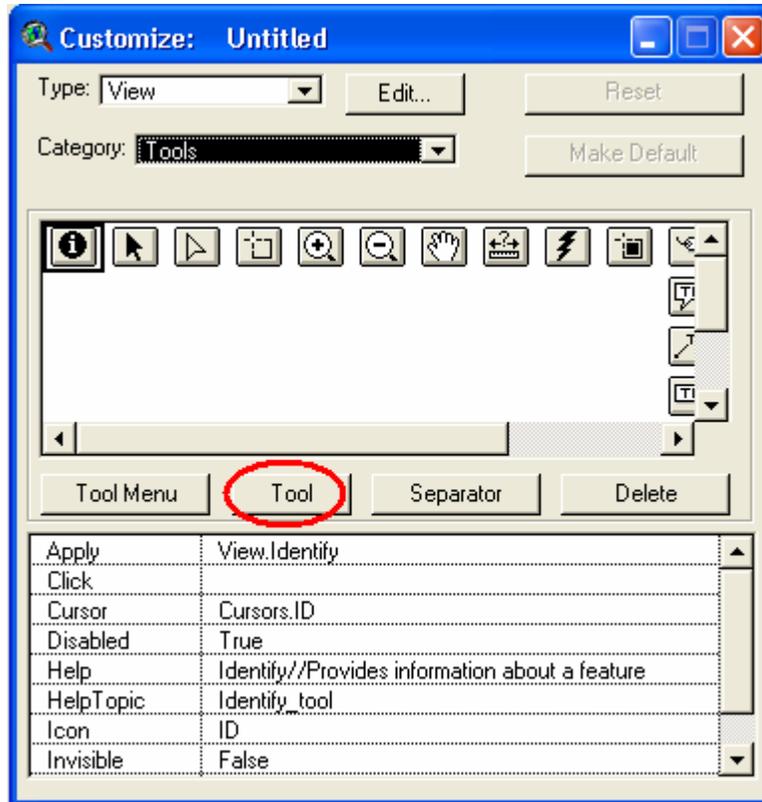


- iii. Click the pull-down menu "Scripts", then "Load Text File";
- iv. Navigate to the cd-rom drive and select the area calculation arcscript, (area.ave) (the script that makes the area calculation operation). The script text then loads into the open window;
- v. Click the check symbol button to compile;
- vi. Double click in the empty space to the right of the icons. (See Figure B 20). The Customize dialog form will then be displayed. (See Figure B 21).

Figure B 20 Double click in the empty space to the right of the icons

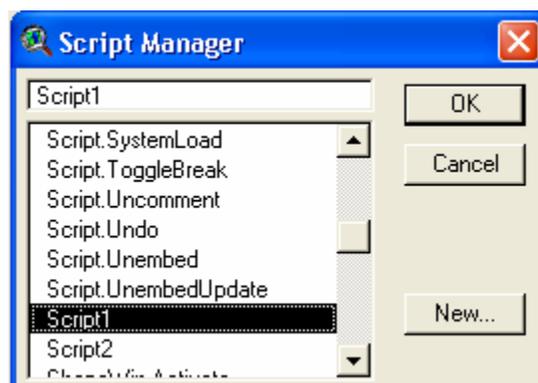


Figure B 21 customize dialog form.



- vii. In the Customize dialog, in the “Type” drop-down menu select “View”. In the “Category” drop-down menu select “Tools”;
- viii. Click the Tool button in the center of the form (circled in red in Figure B 21);
- ix. Move the new blank button all the way to the right;
- x. In the text lines at bottom: Double click “Apply”, this will then bring up the “script manager” box. (See Figure B 22)

Figure B 22 Script manager box



- xi. Scroll to and select “script 1” (or latest script number from step (ii), above). Click “Ok”;
- xii. Double click the “Click” option, scroll to and select “script 1”, click “Ok”;
- xiii. Double click the “Cursor” option, select a cursor style that you like;
- xiv. Double click the “Icon” option and select an icon that you like. Then close the customize dialog box.

The new area calculation icon has now been installed.

7) Using the created new Arcscript function

First highlight the theme that contains the digitized polygons and the road buffer. Then click the created button, next click anywhere on the layer in the view. This automatically adds a field in the attribute table of the theme with the area calculated. To collect the sum of the total area of the polygons, highlight the field header and then go to the pull-down menu “field” and select “statistics”. This will bring up a box with statistics; among the number is the sum of all polygon areas in the theme.

To calculate the percentage of impermeable land from the study region, the newly calculated sum of the buffer and new polygons has to be divided by the total area of the region under study. Multiply the result by 100 and the resulting number will be the percentage of impervious land in the region.

Note: If the area of the study area is not known, the area of the study region must be calculated, following the same steps as for the area calculation of the digitized polygons. (Do this by activating the study area polygon, and clicking on it with the area calculating tool, previously created.)

Appendix C Land Classification using PCI Geomatica and Erdas Imagine

1) Required Data

To begin the user will require the following files:

- Geo-referenced Ortho-photos covering the selected region of study
- GIS boundary file (polygon) for the region of study (sub-watershed)
- Impervious surfaces to be classified include:
 - Houses, buildings, factories & all structures.
 - Pools, arenas, tennis courts.
 - Paved roads, driveways, parking lots.
- Basically any other human-made objects that are permanent that does not allow water to penetrate into the ground.

In order to complete this type of analysis, the capacity of a computer is significant. This analysis was completed on a computer that had 240 GB disk space, 1 GB of memory, and 2.4 ghz processor. The processes can be run on a computer of less capacity, however the length of time required to complete each process would increase.

2) Preparing the data for in Erdas

In order to complete a land classification, the images files must first be mosaiced together and then clipped to the sub-watershed or boundary file. These processes are completed in Erdas Imagine.

(b) Mosaic in Erdas

- i. From the main Erdas toolbar select Data Prep Tool
- ii. In the Data Prep Tool, select Mosaic Images
- iii. In the Editing drop down menu select Image List
- iv. From here select Add Images, then you need to add your images to the list. You may need to change the type of file extension, so your images are available to you. Most often images are in SID, TIFF, GIF, or JPG formats. Erdas will accept any of these image formats, as well as several others.
- v. Once you have added all of your image files to the list, click Add at the bottom of the window, then close. Your images should now be added to the Mosaic Tool file window. They will not appear as actual pictures, rather just an outline, and will fit together in the correct Geo-referenced order.
- vi. Now save this file, from the File drop down menu, select Save As, find the directory, and name the file. It will save it as a .mos file.
- vii. From the Process drop down menu select Run Mosaic, define the new file name and select ok.
- viii. This will begin the mosaic process, which depending on your computers capabilities and the size and resolution of your images can take up to several hours.

(c) Clipping in Erdas

- i. Back in the main Erdas toolbar, open a new Viewer;
- ii. Open you new mosaic file, then the boundary file on top (which is a .shp file);
- iii. Ensure that the boundary file is entire covered by the new mosaic images;
- iv. Click on the boundary file, which should select it and highlight it in yellow;
- v. From the Viewer select the AOI drop down menu, and Copy Selection to AOI;

- vi. Then from the File drop down menu go to Save, then Save AOI Layer AS, and name this file the boundary file name. Then close this Viewer;
- vii. Back in the main Erdas toolbar, open Data Prep;
- viii. Select Subset Image;
- ix. The Input File should be the mosaic image file, and define a new output file, which will consist of the images, cut to the boundary file;
- x. At the bottom of the window, Select the AOI, select the AOI source as an AOI File, then open the AOI file you just created;
- xi. This will begin the mosaic process, which depending on the computers capabilities and the size and resolution of the images can take up to several hours.

The images are now ready to import into PCI for classification.

3) Preparing the images in PCI

In order to use the image files created in Erdas, they must first be imported to a PCI format, then channels must be added to the images in order to complete the land classification.

(d) Importing the image files

- i. From the main PCI toolbar, open Focus (icon looks like a globe being opened);
- ii. From the File drop down menu, select Utility, the Import;
- iii. Select your Erdas image to be imported (this will be an .img file), then define your new output PCI file;
- iv. In the Format Options, select Pixel Interleaved, and in the Pyramiding Options, select Disable Pyramiding;
- v. Now click Import. As noted before this process can be lengthy given the considerations discussed above.

(e) Adding Channels

- i. From the main PCI toolbar, open Xspace, (icon looks like a computer processor);
- ii. From the Utilities drop down menu, select Locate Tasks, search for PCIMOD, once found, activate;
- iii. In the File section, select the new PCI .pix file, in the PCIOP section enter ADD, and in the PCIVAL section type 2;
- iv. Click status to ensure that everything is set up correctly, then click Run to proceed with the processing;
- v. This will add 2 channels to your image file. By adding these channels it will increase the file size, however they are necessary to write the training areas and the classified image.

4) Conducting the Land Classification

The images are now ready to run a classification. The time required to complete this process varies depending on how familiar users are with analyzing Ortho-photos, with enhanced knowledge, the images will be easier to read as to what types of coverages are occurring.

(f) Running a Classification

- vi. From the main PCI toolbar, open Focus, from the Tools drop down menu select Image Classification, and the Supervised;
- vii. Select your PCI .pix file to be classified;

- viii. In your Session Configuration, define a name for your classification, then select bands 1, 2 and 3 in the Input Channels column, then select one channel for your Training Sites, and the last channel for your Output Channel;
- ix. In your Training Site Editing Window, in the Class Drop Down Menu, select New, to add a class, such as “covered surface” or “natural areas”. Also select appropriate colours for each class, as these will be the colours used once the entire image is classified;
- x. You will now be working between the Training Site Editing Window and the Project image window which contains your reference image. On the Training Site window select the class you would like to work with (by clicking on it);
- xi. In your reference image go to the View drop down menu, and then Zoom to, you must select 1:1 resolution to select training sites. Then you find areas representing the class you are working on and select them with the new polygons tool;
- xii. You will do this for each class. The key is to select very small and numerous samples for each class, ensuring that each sample is as homogenous as possible. Remember to save often, which will retain your training sites in the file;
- xiii. When you have completed collecting the training sites, then in the Training Site Editor under the Tools drop down menu, you can run a Classification Preview. Use a Maximum Likelihood Classification with Null Class. The null class is necessary, because of the no data areas surrounding the polygon (black areas);
- xiv. The Classification Preview provides you with an opportunity to examine if your training sites are accurate enough or not. This can be determined with a review of the reference image. By means of selecting a site on the reference image and considering if it is classified properly in the classified image;
- xv. The training sites may have to be refined several times, depending on the capabilities of the user;
- xvi. Once the user is satisfied with the preview, the Classification can be run. This is done by right clicking on the Classification MetaLayer in the reference image window. Select Maximum Likelihood in the Algorithms sections and Null class in the Parameters section. Also ensure that Show Report is selected. Then select Classify;
- xvii. This will produce the Classified Image, and the result will show in a new window;
- xviii. Once the classification is complete, a report will be generated containing information as to the number of pixels for each class. This is used to calculate the area percentage for each class, thus determining it's coverage for the watershed.

(g) Running and Accuracy Assessment on the Classified Image

- i. From the main PCI toolbar, open Focus, from the Tools drop down menu select Image Classification, and Post Classification Analysis, and the Accuracy Assessment;
- ii. Select your new classified image to assess.

Operations section

- i. In the Select Classified Image, select the channel that contains the classified image (this will likely be channel 5);
- ii. In the Load Reference Image, select the channels that contain the original image (these will be channels 1,2,3, make sure to select them in this order);
- iii. Click Generate Random Sample. It will provide you with an option of how many points to select. This is recommended that 100 points per class be used, therefore for this study, it would be 200 points;
- iv. This will generate points across the reference image, then using the classes you have already created you will identify each point as the correct type of classification;

- v. Once you have completed all of the points, you can run the Accuracy Assessment from the Produce Accuracy Report. You must click on each of the types of reports before they will be generated. PCI will compare each of the random sample points to the same point on the classified image and show if the classified image has classified correctly based on the classification you have given to the random point on the reference image;
- vi. There are three types of report available, all of which detail the information in a different way;
- vii. The Error Matrix will short list each class and the incorrect points which fell into that class, and from which class it was incorrectly listed;
- viii. The Random Sample Report will provided the each random point, it's geo-referencing as well as the pixel numbers, and the class assigned to it by the classification, and the accuracy assessment;
- ix. The Accuracy Statistics provide the overall accuracy percentages and confidence interval, as well as the producers and users accuracy percentages for each of the classes.