IMPERVIOUS SURFACE METHODOLOGY

A Methodology for Defining and Assessing Impervious Surfaces in the Raritan River Basin

**New Jersey Water Supply Authority, for the
Raritan Basin Watershed Management Project**

May 2000

METHODOLOGY FOR DEFINING AND ASSESSING IMPERVIOUS SURFACE AREAS
TABLE OF CONTENTS

EXECUTIVE SUMMARY

In an effort to estimate and evaluate impervious cover throughout the Raritan Basin, this methodology was developed to explore the technical and policy decisions involved in the estimation process.

This methodology defines impervious surface areas, states reasons to be concerned about impervious cover, and presents several methods of deriving impervious surface area measurements at the Basin-wide scale, at the subwatershed level, and at an even smaller scale for rapid watershed improvement projects.

Impervious surface areas will be analyzed and mapped for the Raritan Basin project using the following approaches:

- The Basin-wide analysis will be conducted at a HUC-14 (subwatershed) level for the entire Basin and will be aggregated to HUC-11 (watershed) and Watershed Management Area levels. The analysis will include the following:
  - NJDEP 1995/97 Land Use/Land Cover Data
  - NJDOT Road Network Data (to determine the amount of impervious surface attributable to roads). Other supplemental NJDOT data include the following, Straight Line Diagrams, Congestion Management Systems, Pavement Management Systems
  - Analysis of 1st and 2nd order streams using Digital Elevation Model to define their watersheds (if feasible)
- The subwatershed analysis will be conducted for a select few subwatersheds if there is a need based on the Basin-wide analysis, and if time/costs permit. The subwatershed analysis would include the following:
  - Options for Analysis:
    - Refine 1995/97 Data – determine what impervious surfaces don't contribute directly to stream flow
    - Update 1995/97 Data – update to current conditions using new imagery and building permit data
    - Create new layer – digitize exact impervious surfaces using 1995/97 aerial photography
    - Create new layer – use new (1999) satellite imagery to digitize exact impervious surfaces
  - Additional components used in the subwatershed analysis
    - Storm sewers – to understand which surfaces cause flow to streams
    - Building permit data – to estimate impervious surfaces for new development
- In addition to the subwatershed analysis, a more detailed analysis can be conducted as part of rapid watershed improvement projects. This analysis would include the following:
  - Review of subdivision plans and soil erosion certifications
  - Incorporation of data from USGS National Water Quality Assessment study

ACKNOWLEDGEMENTS

Primary Authors:

Tom J. Stanuikynas, Geographic Information Specialist, New Jersey Water Supply Authority

Daniel J. Van Abs, Ph.D., Manager Watershed Protection, New Jersey Water Supply Authority

Contributing Author:

Deborah J. Newcomb, Watershed Protection Specialist, New Jersey Water Supply Authority

An extended "thank you" to the Raritan Basin Watershed Management Project Characterization Committee and Project Team for all of their comments, hard work and suggestions. Project Team members include:

- New Jersey Department of Environmental Protection
- New Jersey Water Supply Authority
- North Jersey Resource Conservation and Development Council
- Rutgers Center for Environmental Communication
- South Branch Watershed Association
- Stony Brook-Millstone Watershed Association
- United States Department of Agriculture – Natural Resources Conservation Service
- United States Geological Survey
- Upper Raritan Watershed Association

1.0 DEFINITION OF IMPERVIOUS SURFACES

Impervious surfaces are defined in watershed management as surfaces that prohibit the movement of water from the land surface into the underlying soil or dirt. Buildings and paved surfaces (e.g., asphalt, concrete) are considered impervious covers. A natural condition (e.g., bedrock close to the surface, very dense soil layers such as hardpan that restrict water movement) is not considered "impervious cover." As such, the watershed field applies the term "impervious cover" to conditions that are created by human action. Natural conditions are addressed in other ways, such as through the assessment of ground water recharge. One major benefit to the focus on human structures is that buildings and pavement are fairly easy to identify using aerial photography while subsurface, natural conditions are not as obvious.

More difficult to fit into the discussion are "semi-hardened" surfaces that greatly impede water flow and are also caused by human action. Examples include compacted soils in developed areas, which can be nearly concrete-like in their imperviousness. Gravel roads, driveways and parking lots can also have highly compacted surfaces.

In this methodology paper, the definition of percent total impervious area (%TIA) follows current thinking that the major issue revolves around the density of impervious cover within a watershed, rather than the actual area (e.g., square feet) of impervious cover. A related term is "percent effective impervious area" (%EIA) which recognizes that some impervious areas are completely surrounded by pervious areas and therefore have less of an impact on aquatic ecosystems. "Effective impervious area" is basically the impervious cover that provides stormwater flows fairly directly and quickly to streams. For example, a paved basketball court surrounded by grass lawn at a school might have less impact than the same court surrounded by paved parking areas. A look at %EIA could exclude the basketball court surrounded by a grass lawn from the estimate of impervious cover.

1.1 Reasons for Concern About Impervious Cover

Impervious cover has been implicated in a number of significant watershed impacts. Most of these impacts are related to hydrologic changes – the flow of water into and within the stream system. Increased impervious cover generally results in more stormwater runoff and less ground water recharge, unless deliberate steps are taken to mitigate those impacts. More runoff, in turn, increases stream flows during storm periods. Stream banks erode, more sediment is carried into the streams from surrounding lands, and aquatic habitats are disrupted and degraded. Less recharge means less ground water discharges to streams during dry periods. The reduced stream flow and more extreme stream temperatures will stress aquatic ecosystems. In addition, pollutants tend to be more concentrated because dilution is reduced. When stormwater moves more quickly into streams, it also has a greater capacity to carry nonpoint source pollutants into the streams. High levels of impervious cover are associated with dense development, which will have greater pollutant loads available for transport to those streams. Both higher storm flows and lower dry weather flows can have water supply impacts.

Ecological studies on the impacts of impervious cover on aquatic ecosystems have been completed in numerous parts of this country. Tom Schueler and his colleagues of the Center for Watershed Protection have been compiling and interpreting the results. Although every ecosystem will react somewhat differently, and although most impacts should be described statistically rather than through the use of fixed numbers, Schueler has found that increased impervious cover is strongly related to increased degradation of aquatic ecosystems. Further, he has suggested certain levels of impervious cover above which stream degradation should be expected (approximately 10 percent) and above which extensive and perhaps permanent stream damage should be expected (approximately 25 percent), for watersheds of approximately 10 to 20 square miles.[1] Impervious cover is used as an indicator; the assumption is that the hydrologic changes and nonpoint source pollutant loadings from such land cover cause most of the ecosystem degradation, rather than the impervious cover itself.

Some of the research indicates that the situation is considerably more complex, and that multiple factors influence aquatic ecosystem health. Pollutant loadings from point sources are certainly one such factor. Others include stream channelization, removal or presence of large woody debris, road and utility crossings, etc. The expectation is that these additional factors may explain some of the variability in ecosystem impacts demonstrated by the impervious cover research. (Some of these factors are addressed in other technical reports for the Raritan Basin Watershed Management Project.) However, impervious cover does seem to explain a great deal of stream damage in these studies as well. Table 1 in the Appendix is a schematic of how various factors may play into the health of aquatic ecosystems. Based on the research available, it is important to note that impervious cover is an indicator of the potential for degradation – it is not by itself deterministic.

Unfortunately, very little research on this topic has been performed in New Jersey. The United States Geological Survey's Trenton Office has been pursuing this topic through its National Water Quality Assessment (NAWQA) project in New Jersey and New York. The first step assessed correlations between water quality and aquatic ecosystem degradation, while the second step looked into correlations between impervious cover and degradation. In addition, the New Jersey Geological Survey (NJGS) has developed a method for identifying and mapping areas that are important for ground water recharge. This method (described in the GSR-32 report) will be used to identify ground water recharge areas for the Basin.

1.2 Discussion of Options

There are a variety of options available for assessing impervious cover in the Raritan River Basin. However, the more complex the approach is, the higher the cost. Several of the options could be implemented in specific subwatersheds as case examples, rather than implementing them over the entire basin at great expense. The approaches that follow include those that will be performed for the entire Basin as well as those that may be performed at the subwatershed level based on complexity and cost.

2.0 BASIN-WIDE ANALYSIS

The analysis for the entire Raritan Basin will be performed at the HUC-14 (subwatershed) level and will aggregate up to the HUC-11 (watershed) and Watershed Management Area levels. Two approaches used to derive estimates of impervious cover for the Basin are discussed in this section. The first approach relies on readily available land use/land cover information. The second approach calculates the amount of impervious cover associated with the transportation network. The two methods are described below and will be used in combination for this project.

2.1 NJDEP 1995/97 Land Use/Land Cover Data

Discussion

The New Jersey Department of Environmental Protection (NJDEP) has generated a statewide Geographic Information System (GIS) data layer containing land use/land cover (LU/LC) classifications. The LU/LC data were digitized using 1995 and 1997 digital ortho-photo quarter-quads (DOQQ) and LU/LC values were assigned to individual polygons at a one-acre minimum mapping unit. In addition to LU/LC codes, an Impervious Surface (IS) value was estimated for each polygon. The estimates were made visually based on the 1995/97 DOQQ's and are represented in 5% increments, ranging from 0-100. All water categories are coded 0. Any polygon that contains pavement (e.g., a roadway) within its boundaries or has a roadway for a boundary will be assigned an IS value of no less than 5. The Quality Assurance/Quality Control process consists of frequency analysis of the IS values per various LU/LC categories to determine if the values are in line with the category ranges.[2] Before the data are officially released for public usage, they will be field checked by the contractor (Aerial Information Systems, Inc.) that developed the coverage.

Methodology

Currently, the NJDEP LU/LC data is the most useful source of impervious surface estimates available and will be used to conduct the analyses for the entire Basin. The data are in Environmental Systems Research Institute's (ESRI) ArcInfo and ArcView GIS format and can be downloaded at no charge via the Internet. All polygons are individually measured for both %TIA and total IS acreage. The format is consistent with other NJDEP GIS data that are widely used throughout the State of New Jersey. The one-acre accuracy is not a concern for mapping purposes, since most data used for this project have been at a resolution between 2-5 acres. However, the age of the data is cause for some concern. To rectify this deficiency and account for growth in the Basin, other forms of data may be incorporated into the mapping process at the subwatershed level. These other methods will be discussed in later sections of this methodology.

2.2 Improving Estimates Using Roadway Data

Discussion

The second component for assessing %TIA for the entire Basin is to consider to what extent paved roadways affect the amount of impervious surface cover in the Basin. Calculating impervious surface estimates exclusively for the road network will supplement the NJDEP data results twofold. Not only will it be utilized to spot check areas of particular interest, it will also allow for more in-depth analyses. As described in the previous section, the NJDEP LU/LC coverage assigns a single Impervious Surface (IS) value for each land use polygon. Many of the multi-lane, divided highways are digitized as separate land use polygons and therefore have unique IS values. However the remaining roads (which encompass a large percentage of the total) are not dealt with as separate areas but are "absorbed" into the land use polygon in which they are located. Therefore, the amount of impervious surface these roads contribute to the polygon is combined into the total IS value.

As a result, a separate impervious surface cover layer specific to the road network will be created. To accomplish this task, a segmented, linear GIS coverage that contains the entire road network, including off-ramps, is required. The New Jersey Department of Transportation (NJDOT) possesses such data. More accurate than the commonly used TIGER files, the NJDOT line work was digitized from 1991 aerial photography. Utilizing a GIS, the NJDOT road layer would provide the basis for calculating the total square mileage of roadway within the Basin, which in turn could be used to estimate the amount of impervious surface attributed to roads. The first step would be to estimate the total miles of roadway (length) within the Basin using a simple GIS query. Using attributes, which exist within the NJDOT road layer, and a basic knowledge of the surrounding geography, one can further analyze the data by road type (Interstate, turnpike, freeway, highway, and local).

The second variable needed for this equation is road width. Remembering that the NJDOT road layer is linear, which by definition is one dimensional, road width data will have to be extracted from another source. Since road widths vary greatly due to numerous conditions (number of travel lanes, shoulders, parking, intersections, turning lanes, acceleration and deceleration lanes, etc.), an average road width for each road type is used. The techniques that will be used for approximating average road widths by road type are discussed below.

1998 NJDOT Straight Line Diagrams (SLD) – The NJDOT Straight Line Diagrams contain much of the data needed to conduct this analysis. Functional class, speed limit, number of lanes, lane width, shoulder width, median type, median width, and traffic volume are provided for all Federal Aid System roads. The Federal Aid System includes all Interstates, U.S. Highways, State Highways and a few county and local roads. Due to the vast amount of incremental changes in each field for all road segments, the attribute tables encompass hundreds of pages. As of now, this information is in a format that is not compatible with GIS. However, the NJDOT does provide some of the SLD data, including road widths, in a spreadsheet format that is suitable for querying. This will be a valuable resource for spot-checking specific roads.

NJDOT Congestion Management Systems (CMS) – Utilized by transportation planners to map traffic congestion, this source of data includes many of the same data fields as the SLD. Data fields are averaged over large segments for a selected quantity of primary arterials. Fewer line segments are easier to mange and therefore will provide average road width estimates quickly and effectively.

NJDOT Pavement Management Systems (PMS) – This dataset includes total estimates for paved surface area using centerline mile, lane miles, and an estimation of road width for selected road types, including off-ramps. This data is a useful tool for spot-checking final results.

Once the road widths are estimated, the simple task of multiplying the total length by the average width for each road type would produce the square mileage of impervious surfaces attributed to the highway network.

Methodology

Examining the NJDEP LU/LC data as a standalone layer will not reveal the amount of impervious surface that is directly produced by roads. In order to find the impervious surface area of the road network, a separate analysis will be conducted using the NJDOT road layer to provide the total miles of roadway for each road type. A new field will be created in the NJDOT road coverage for "average road width." An analysis of the NJDOT CMS was used to produce the "average road widths" by road type. The estimates that will be used for the Basin analyses are as follows:

NJ Turnpike	140 feet wide
Interstate Highways	110 feet wide
Other Freeways	90 feet wide
Major Arterial Highways	60 feet wide
All Other Roads	36 feet wide

Depending on the road type, the "average road width" value will be assigned to each segment. The length and width of each segment will then be multiplied to produce a total square mileage for each segment. The NJDOT SLD will be referenced for more precise calculations. Data from the NJDOT SLD can be used for roads that do not fit the average ranges or to spot-check certain segments. The final output of the analysis will be compared to the data from the Pavement Management System for quality assurance/quality control purposes.

2.3 Analysis of 1st and 2nd Order Streams

If available data permit, analyses will also be done for the watersheds of all 1st and 2nd order streams within the Basin. To conduct the analyses at this level, use of the USGS Digital Elevation Model (DEM) would be required. However, due to technical inadequacies within the DEM, accurate results may not be able to be produced. First and second order stream analyses will not be conducted until a corrected DEM is available.

3.0 SUBWATERSHED ANALYSIS

A small number of subwatershed pilot studies may be undertaken to offer a more detailed investigation of impervious surface conditions throughout the Basin. Examining a much smaller land area will allow more focused analyses that would be too cost-prohibitive at the Basin scale. Depending on the outcome of the Basin analyses, the value of subwatershed pilot studies will be determined. If pilot studies are desirable, time and cost constraints will influence the extent of analysis.

3.1 Methods for Analysis

There are several ways to perform a more precise, subwatershed analysis. Methods will be described from the least costly and time intensive, to the most costly and time consuming. However, the more labor intensive the approach, the better the end product. Methods for analysis include the following:

- Refining or updating the 1995/97 LU/LC data – Corrections and additions to the 1995/97 LU/LC data will improve impervious surface results and can be accomplished in two ways.
    - Using the same 1995/97 DOQQ's the NJDEP used to digitize their coverage, existing polygons can be manipulated and re-worked to better portray conditions found on the DOQQs. For example, %EIA can be extracted from %TIA. Think of a polygon that was digitized as an "Educational Institution." This polygon may now be split into several parts including buildings, grass fields, parking lots, and hard surface recreation areas, which could not be done previously. (See 3.2.1 below)
    - By obtaining new satellite imagery and building permit data, the same analysis can be done for current conditions.
- Digitizing new coverages – Instead of improving the NJDEP data, the idea of creating an entirely new GIS layer to assign impervious surface values is another option that can be addressed in two ways.
    - Digitize new polygons using 1995/97 DOQQ's as a base, showing the actual boundaries of impervious surfaces instead of assigning a general value to each LU/LC.
    - Digitize new polygons using new (1999) satellite imagery as a base.

3.2 Components Used in the Subwatershed Analysis

3.2.1 Storm Sewers

Discussion

Research by the USGS indicates that the presence of stormwater sewers can have a major effect on the impact of impervious cover. Storm sewers can provide a direct link between impervious surfaces and streams. From the perspective of ecological impacts, the same level of impervious cover can have very different impacts depending on the existence, routing and management of storm sewers. As an example, a road with grass swales that drain to wooded areas will contribute less stormwater (and less quickly) to streams than a similar road with curbs, storm drains, storm sewers and direct outfalls to streams. The problem, of course, is the cost of mapping in GIS the location of storm sewer outfalls, the collection areas for those outfalls, and the existence of any management devices (e.g., detention basins, grass swales) prior to the outfalls. Considerable experience exists in New Jersey regarding this kind of mapping. The Sewage Infrastructure Improvement Program mandated the mapping of outfalls and collection systems for both stormwater and wastewater systems in 84 coastal municipalities. NJDEP provided millions of dollars for this project, which covered a smaller geographic area than the Raritan River Basin and did not include the mapping of stormwater basins, swales and similar devices.

Methodology

There is interest in the feasibility of determining whether road edging (curbs versus grass swales), and drainage methods (storm sewers versus drainage to open space or detention basins) can be addressed in this project. If time and costs permit, an analysis will be conducted in a small number of subwatersheds where the affected municipalities have already mapped their storm sewer systems to determine how storm sewers can change the assessment of %TIA to %EIA. Municipalities and soil conservation districts in the seven county region would also be contacted to determine the amount of data available and in what format. From the collected data, it would be determined whether stormwater transport is common from impervious cover that is remote from streams, or whether it is a rare occurrence that need not be analyzed in most situations.

3.2.2 Remotely Sensed Satellite Imagery

Discussion

Another method for analyzing impervious surface areas for specific subwatershed case examples would be to use remotely sensed satellite imagery. In this scenario, digital images would first need to be classified for %TIA which would entail having the imagery classified for the various categories of LU/LC and then given a %TIA measurement based on the average %TIA for each LU/LC type. The University of Connecticut Cooperative Extension System's *Nonpoint Education for Municipal Officials Project* (NEMO) has suggested some general guidelines for assigning a percent imperviousness.

Methodology

If time and resources permit, and if the data are in an appropriate resolution, satellite imagery data may be used at the subwatershed level to identify and target areas requiring detailed investigations.

3.2.3 Building Permits and Subdivision Approvals

Discussion

Municipal and county building permit data would provide additional information on the location and potential for new development sites throughout the Basin. By reviewing available building permit and subdivision approvals (for both built and pending projects), there would be a better idea of how much *more* impervious cover has been built or is anticipated in a selected subwatershed.

Methodology

Again, if time and resources permit, building permits in select municipalities or counties would be reviewed and the results incorporated into subwatershed case example analyses.

4.0 OPTIONS FOR RAPID WATERSHED IMPROVEMENT PROJECTS

In addition to the subwatershed case examples, there is a possibility, that more detailed analyses may be conducted for smaller scale projects in the Basin. These smaller scale projects (referred to as rapid watershed improvement projects) are driven by critical needs and can be implemented quickly to restore and protect water resources. Such projects are generally undertaken to help minimize future problems that could harm water resources and the local economy. These actions are taken before the passage of time makes it more difficult and expensive (or even impossible) to implement them. The Raritan Basin Watershed Management Project will be funding up to twelve planning efforts for such projects.

Detailed analyses of impervious surfaces for rapid watershed improvement projects would include a review of subdivision plans and soil erosion certifications at the local or municipal level. Review of these plans and certifications would identify specific developments that have been built, or that have been approved but not built, in targeted areas of the Basin. In addition, the USGS NAWQA study would be used to analyze correlations between impervious cover and degradation that are associated with specific rapid watershed improvement projects.

5.0 CONCLUSION

The methodologies discussed above represent an approach for defining, characterizing and mapping the impervious surface areas of the Raritan Basin. Each methodology has its own unique function in the calculation of %TIA as well as varying levels of complexity, effort, cost and result.

6.0 ACRONYMS

%TIA – Percent Total Impervious Area
%EIA– Percent Effective Impervious Area
CMS– Congestion Management System
DOQQs – Digital Ortho Photo Quarter-quadrangles
ESRI – Environmental Systems Research Institute, Inc.
GIS – Geographic Information System
HUC – Hydrologic Unit Code as defined by the United States Geological Survey
LU/LC – Land Use/Land Cover
NAWQA – National Water Quality Assessment
NJDEP – New Jersey Department of Environmental Protection
NJDOT – New Jersey Department of Transportation
SLD – 1998 New Jersey Straight Line Diagrams
USGS – United States Geological Survey
WMA – Watershed Management Area

7.0 LIST OF REFERENCES

Center for Watershed Protection. 1998. Rapid Watershed Planning Handbook – A Comprehensive Guide for Managing Urbanizing Watersheds. Ellicott City, Maryland.

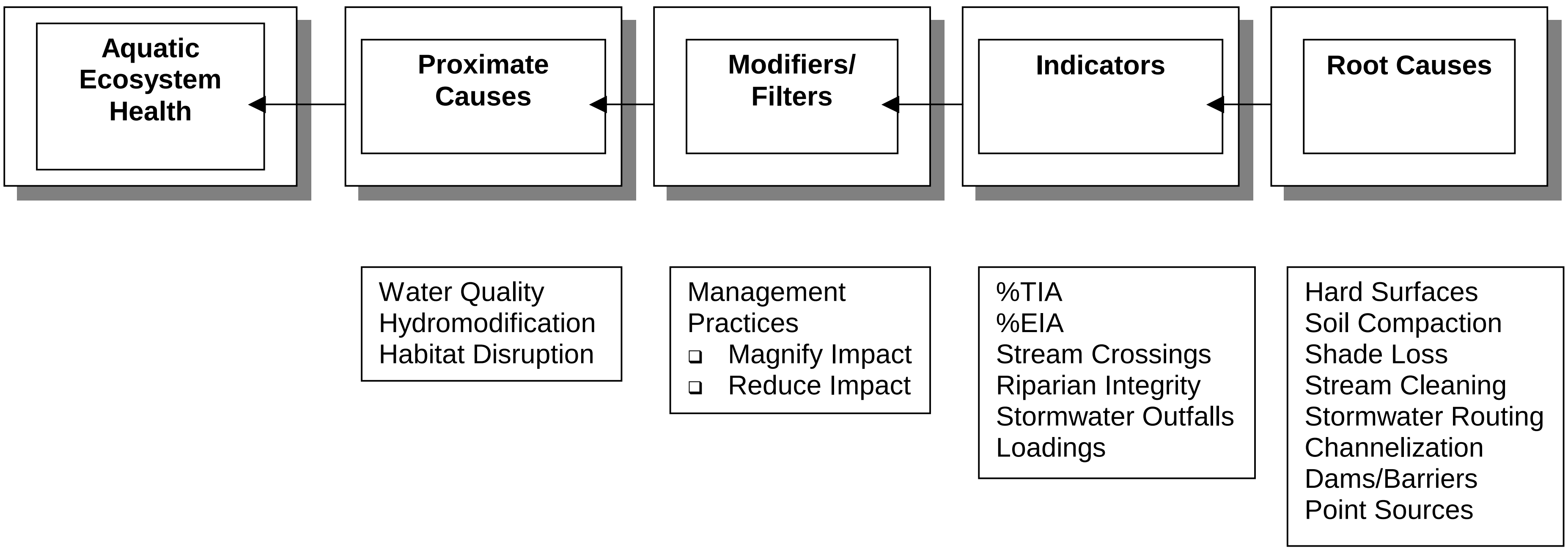
Nonpoint Education for Municipal Officials. 1999. NEMO Technical Paper – Do It Yourself Impervious Surface Buildout Analysis.
http://www.lib.uconn.edu/vol4/CANR/ces/nemo/gis/imperv.html

New Jersey Department of Environmental Protection. 1999. Land Use/Land Cover and Impervious Surfaces for the Lower Raritan/South River/Lawrence Brook Watershed Management Area (WMA-9) New Jersey, 1995/97; Edition No. 1.2. Bureau of Geographic Information and Analysis (BGIA), Office of Information Resource Management (OIRM), NJDEP.

United States Geological Survey. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. Edited by the NJDEP, OIRM, BGIA – 1998.

APPENDIX

Table 1
Schematic of Assessment Targets
Aquatic Ecosystem Impacts



[1] Center for Watershed Protection, 1998
[2] USGS, 1976