NON POINT SOURCE POLLUTION ASSESSMENT – A GEOSPATIAL APPROACH

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ABSTRACT

Urban catchments are exposed to a wide range of pollutants from various sources, which are commonly described as diffused or non-point source (NPS) pollution. This paper describes a geo-spatial methodology applied to a Contaminant Load Model that improves and enhances the current spreadsheet approach developed by the Auckland Regional Council. The geospatial approach leads the Contaminant Load Modelling (CLM) process towards advanced and optimised decision making for determining and responding to the complex NPS pollution issues.

NPS pollution is a significant contributor to water quality degradation and poses a great challenge for control and abatement.

An integrated approach for Catchment Management needs to incorporate Contaminant Load Modeling (CLM) in order to demonstrate a sufficient understanding of impacts of urbanisation and other activities on the environment and in this particular case on stormwater runoffs.

However, NPS pollution assessment techniques require more clarity within the industry and there are a number of challenges such as:

- The need for a consistent approach to analysis, tools and the data to be used in assessments;
- The need for clarity in interpretation, presentation and understanding of the outputs;
- The need for better communication of the technical information to various users and stakeholders.

The geospatial approach enables the collection, analysis and modeling of relevant data with an advantage of combining existing and acquired geospatial data onto a single IT platform, thus enhancing strategic decision making for integrated catchment management.

KEY WORDS:

Non point source (NPS) of pollution, contaminant load model, catchment management, spatial data, geospatial approach

1. INTRODUCTION

This paper describes Non Point Sources of Pollution (NPS) assessment approach using the spatial analysis model developed in ArcGIS software and applied to the New Lynn catchment as a pilot case study. The assessment is based on the spatial and non-spatial data analysis using Council records and the Contaminant Load Model (CLM) guidelines developed by Auckland Regional Council (ARC).

Urban non-point source (NPS) pollution represents a significant contributor to water quality degradation. Catchment managers addressing NPS are increasingly in need of effective catchment management strategies, planning studies and tools to evaluate the impact of existing and future developments on their surface water quality. Contaminant load analysis is an integral part of any Integrated Catchment Management Study. Spatial information, analysis and models offer the advantage of combining existing and acquired geo spatial data onto a single platform thus enabling strategic decision making about integrated catchment management.

The main objective of this study is to apply a spatial method for the calculation of NPS pollution using the ARC CLM yield rates and load calculation recommendations.

Utilising the proposed spatial methodology would ultimately enable practitioners to achieve costs and time savings in an optimised decision making process involved in determining pollutant issues within the catchment and achieving greater compliance with ARC's requirements.

In applying this approach, the Council would be required to standardise input from the existing spatial data for inclusion into the NPS assessment. The spatial analysis approach provides results that are recorded into a database that contains required attributes for land use, contaminant loading rates, source types pollutant treatment methods and others. This approach provides a greater flexibility and overview of the analysis process and adds immense capability for mapping and visualization of relevant parameters and trends.

2. BACKGROUND

Urban catchments are exposed to a wide range of pollutants from various sources, which are commonly described as NPS pollution. NPS represents a significant contributor to water quality degradation, which represents a unique challenge for control and abatement. It originates from wide areas and the pollutant transport is highly variable.

A contaminant load analysis is an integral part of any Integrated Catchment Management Study (ICMS) and ARC standard requirements. ICMS needs to demonstrate an understanding of contaminant loads from diffused sources typically correlated with urban land use types. In practice this requirement has met a variety of challenges such us a consistent approach to analysis, tools and data to be used in analysis and interpretation, including a clear understanding of the outputs by various users and stakeholders.

A combined study including findings of three separate projects in Auckland was commissioned by ARC in 2005. This study provided most of the data required to enable pollutants and metal sources in urban catchments of different land uses to be identified and quantified (Timperley et al, 2005). From this study a contaminant load model, in a spreadsheet format, was developed with the aim of simplifying the computation of sediment, zinc, copper and petroleum hydrocarbon loads within a given land area. The model brings together the data presently available in Auckland for contaminant yields; the amount of contaminant produced per given source area in a given time, (e.g. g/m2/ annum) and the efficiencies of various management options for reducing the amounts of contaminants leaving a site (Timperley, 2006).

Further work on integration of various models into the regional harbour sediment / contaminant accumulation model (USC- 3) was published in the following papers:

1. "Stormwater Contaminant and Sediment Load Modeling in the Central Waitemeta and South-eastern Manukau Harbour Catchments" (Timpereley et al, 2009);

2. "Overview of Predicting Long Term Contaminant Runoff and Accumulation in the Central Waitemata and Southeastern Manukau Harbours" (Johnathan Moores at al 2009);

3. Distribution of Metal and Sediment accumulation in the Central Waitemata and Manukau Harbours" (Jacquie Reed et al, 2009).

The authors have also explored a relationship between CLM and current harbour modeling that is an ongoing programme run by ARC. Several technical papers were published at the Stormwater Conference in Auckland in 2009. With respect to the harbour modeling, "Outputs from CLM are used as inputs into a regional harbour sediment / contaminant accumulation model (USC- 3)" (Timperley et al 2009), and

"The CLM version that was applied in the CWH and SEM studies was developed specifically for these studies. The updated version will be released in a spreadsheet format as Version 2 of the CLM." (Timperely 2009).

We have identified that the CWM study includes the New Lynn area, which is also used as a pilot study area for this geospatial assessment approach.

Based on these technical papers the authors considered that the geospatial approach would be compatible with ARC requirements.

Data inputs for the CLM spreadsheet model include the total site area of various contaminant source types (different land use types), the length of each category of roads, the contaminant management options for each source and the fractions of the source and sites areas draining to the management treatment option trains. To be able to obtain these data inputs, it is necessary to derive data from a spatial information database. In order to present the outputs in a map format it is also necessary to export the results into the spatial GIS database. This "double handling" is considered unnecessary as using the appropriate tools in ArcGIS the spatial approach can be used not only to produce data necessary for input to perform the CLM analysis, but also to calculate contaminant loadings and present them visually.

Spatial analysis methods are widely used for a broad variety of land use related studies. For NPS pollution control and planning, they have been shown to be very effective in targeting and prioritising NPS pollution control resources. For spatial analysis ArcGIS is the software most commonly used.

The geospatial database can be structured and classified through ArcGIS in various data layers such as: soils, land use, surface water, elevations, watershed boundaries, political boundaries and locations of built-up structures, roads, point sources and so on. It enables the creation of additional data layers that can be created or derived from the base data layers. These may include cell slope, slope length, length-slope factor, water quality index and erosion index. Spatial data sets can also be used in a combination with existing hydrological models or on its own in assessment of nonpoint source pollution (Krpo, 2007).

The geospatial analysis method used in this study serves as a means of storing, manipulating and displaying the extensive volumes of spatial data associated with NPS pollutants.

3. STUDY SCOPE AND EXTENT

This paper describes the study which was to develop the Geospatial Analysis Method for CLM and prepare, analyse, compute and present information using ArcGIS. For this purpose New Lynn was chosen as the study area as shown in Figure 1.

Figure 1: Study Area

4. METHODOLOGY

Understanding the different types of data and assessing the quality / capability of data is a key aspect of the spatial approach. The quality of the data inputs will have a direct impact on the resulting outputs. Hence before analysis is performed, an audit of the data should be undertaken to ensure that the right data and formats are being used.

NPS pollution within the study area is represented through different land use types. Table 1 shows land use types (source types) applied in this study as per ARC guidelines.

The Spatial Analysis method developed for this project can be divided into three parts:

a. The database development of:

- Contaminant yields for various source types based on current and future land coverage;

- Reduction efficiency values for various treatment options applied on different source types;

- Input and output datasets.

b. The development of models / tools to select the specific source type (based on land cover), classification of selected source types based on various criteria e.g. slope, roof material type, number of vehicles per day on roads, data linking contaminant yields and different source (land cover) classes, calculation of contaminant source area and calculation of initial contaminant load.

c. Calculation of reduced load based on load reduction efficiency values, initial contaminant load and contaminant source area.

NPS of Pollution
Roofs
Roads
Paved Surfaces other than roads
Urban Grass Lands
Urban Stream Channel
Construction Site (2) open for 6 months/year
Construction Site (3) open for 12 months/year
Stable bush

Table 1: Source Types

4.1 NON-SPATIAL DATA MANAGEMENT

4.1.1 Contaminant Yield Rates

Contaminant yield rates are available from the ARC CLM spreadsheet. Hence the database with contaminant yields for various source types including reduction factors for different management options was developed and stored in the ArcGIS geodatabase. The geodatabase is the common data storage and management framework for ArcGIS. It supports all the different types of data that can be used by ArcGIS such as attribute tables, geographic features, satellite and aerial imagery, surface data and survey results.

The geodatabase therefore offers the ability to store a comprehensive collection of data types in a centralised location, apply sophisticated rules and relationships to the data, maintain integrity of spatial data and integrate spatial data with other IT databases (Perencsik et al., 2005).

Figure 2 shows an example of contaminant yields and reduction efficiencies Geodatabase.

Figure 2: Yields and Reduction Efficiencies Geodatabase

Contaminant yield rates and reduction efficiencies represent non-spatial dataset which must be linked to spatial features to be useable in the analysis. Thus, the geodatabase with the yield rates and reduction efficiencies linked to the study area source types enables computation with relevant factors within each source type area.

4.1.2   Traffic Counts

The other non-spatial dataset needed for this model is Average Daily Traffic (ADT) counts. This data was obtained from the Council and joined to the road shape file, which is a spatial dataset. ArcGIS contains the tools to join tabular data with geographic features and displays the data on the map. Joining data in this case was used to append the fields of traffic counts table to those of 'road' geographic feature through an attribute or field common to both datasets – road names. A number of minor roads lack ADT data but an ADT <1000 was inputted which adequately represents these roads.

4.2   SPATIAL DATA MANAGEMENT

Raster and vector spatial data sets are used in this study to illustrate the landscape and implement various geospatial analysis.

Vector model represents the world with points, lines and polygons. This model is specifically useful for representing features such as parcels, pipes, building footprints, water outlet points and similar. ArcGIS stores vector data as features in feature classes and collection of feature classes.

Raster model represents the world as a surface divided into a regular grid of cells. This model is useful for representing the data that varies continuously. Aerial images, digital elevation models, and slope surfaces are examples of geographic information in raster format.

Vector data layers can be converted into raster data layers and vice versa relying on the conventions that a point may be represented as a single grid cell, a line may be represented as a string of grid cells, and a polygon may be represented as a zone of cells. ArcGIS contains the tools for format conversion working on raster and vector data sets.

Table 2 summarises the base spatial data needed for this model, its availability and source.

Geospatial data feature / File Name	Comment
Contour	The slope analysis is based on the Lidar data contours.
Impervious Area	The impervious area within the catchment is provided in various layers as roads, roofs and other.
Stormwater Line	Stormwater lines data set contains valuable attributes that are used to aid the data preparation; however they are not part of NPS assessment.
Stormwater Point	Stormwater point's data set contains valuable attributes that were used to aid the data preparation; however they are not part of the NPS assessment.
Parcel Boundary	Parcel boundaries with their attributes are provided from Council's Spatial database.
District Plan Zone	District plan zone layer is sourced from the Council's spatial database. This data has been reclassified to suit land cover classes suitable for NPS analysis.
Road Network	Road network layer is sourced form the Council's Spatial database.
Stream/River	Stream River layer are sourced from Council's Spatial database. The land cover (source type) is determined by calculating a typical width of the stream at critical locations.
Building Footprints	Building footprints source from the Council's Spatial database. This dataset was updated with roof material values.
Stormwater Treatment Devices	Locations for the existing stormwater treatment devices were provided. The catchments were determined by observation of the stormwater networks, their discharge points and land contours.
Construction Sites	Railway corridor and the site at the Corner of Astley Ave / Margan Rd were identified as construction site.
Aerial Images	Aerial images are sourced from Council's Spatial database. Used for helping determining the land cover (source type).

Table 2: Spatial data

4.3   MODEL INPUT AND DATA PREPARATION

Table 3 represents datasets created and/or refined to be valid model inputs.

Created Spatial data feature/File Name	Description
Roof	Building Footprints file updated with roof material type attributes
Road	Road network file updated with traffic counts attributes. The layer comprises a number of polylines from which the areas are calculated based on length and code area as per ARC guidelines.
Paved Surfaces other than roads	Impervious Area file updated by erasing roads areas and intersected with District Plan file to assign residential, commercial and industrial LU values

Source Type dataset/codes:
    Urban Grass Lands
    Stable Bush
    Urban Stream
    Road
    Residential
    Industrial
    Commercial
    Construction site – 6 months
    Construction site – 12 months
	District Plan Zone file updated with Source Type Codes

Stormwater Treatment Catchments	Newly created file representing stormwater treatment catchment areas
DEM	Digital elevation model Developed from LIDAR contour data
Slope	Surface slope file derived from digital elevation model and reclassified (i.e. <10; 10-20; 20< degrees)

Table 3: Created Datasets

4.4 CLM - GEOSPATIAL ANALYSIS

Figure 3 shows ArcGIS tools created to evaluate initial contaminant load.
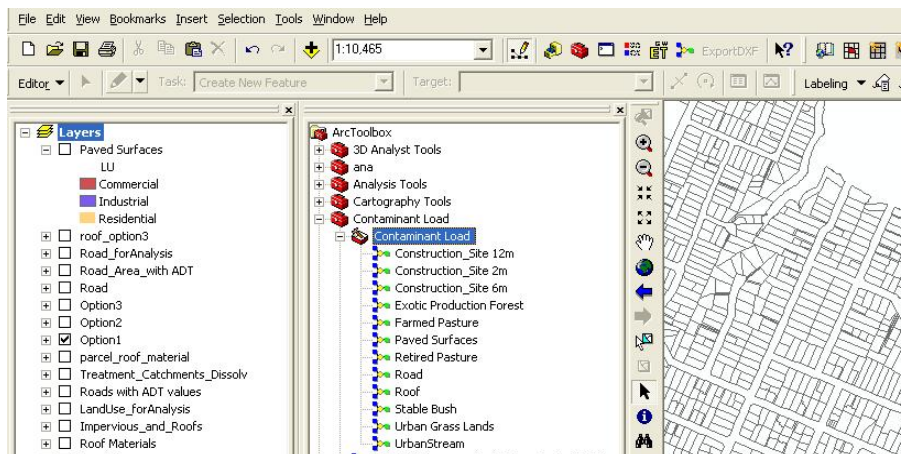

Figure 3: Toolbox

A separate tool is developed for each contaminant source as there is a mixture of various parameters required to evaluate contaminant loads for diverse land use types.

By clicking on the tool e.g. 'Road', a dialog box appears (Figure 4) so that the user can choose the input and output file. Initial contaminant load is calculated and a new road file created with contaminant loads attributes for each segment of the road.
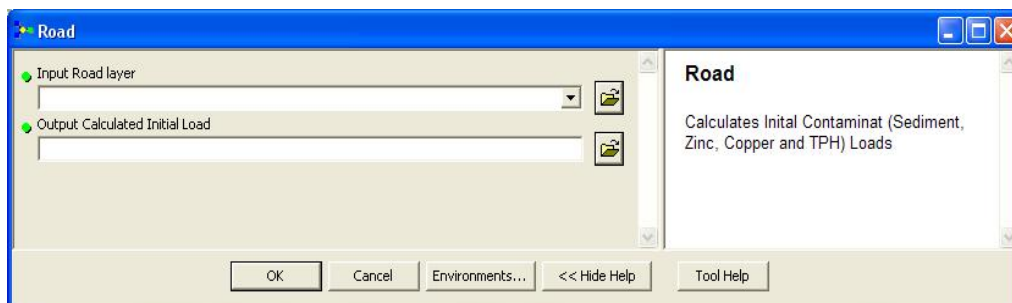

Figure 4: Initial Contaminant Load dialog box

Note that reduced contaminant loads are evaluated based on load reduction efficiency values, initial contaminant load and fraction of contaminant source area (as per ARC guidelines).

5. RESULTS

The analysis included options as follows:

Option 1   Contaminant loads calculated for the current NPS source types

Option 2   Contaminant loads calculated changing NPS source type for the site at the Corner of Astley Ave / Margan Road to a construction site open for 12 months

Option 3   Contaminant loads calculated assuming the site at the Corner of Astley Ave / Margan Road is a fully developed residential site (with assumed 65 % imperviousness – 50 % building and 15 % paved surfaces)

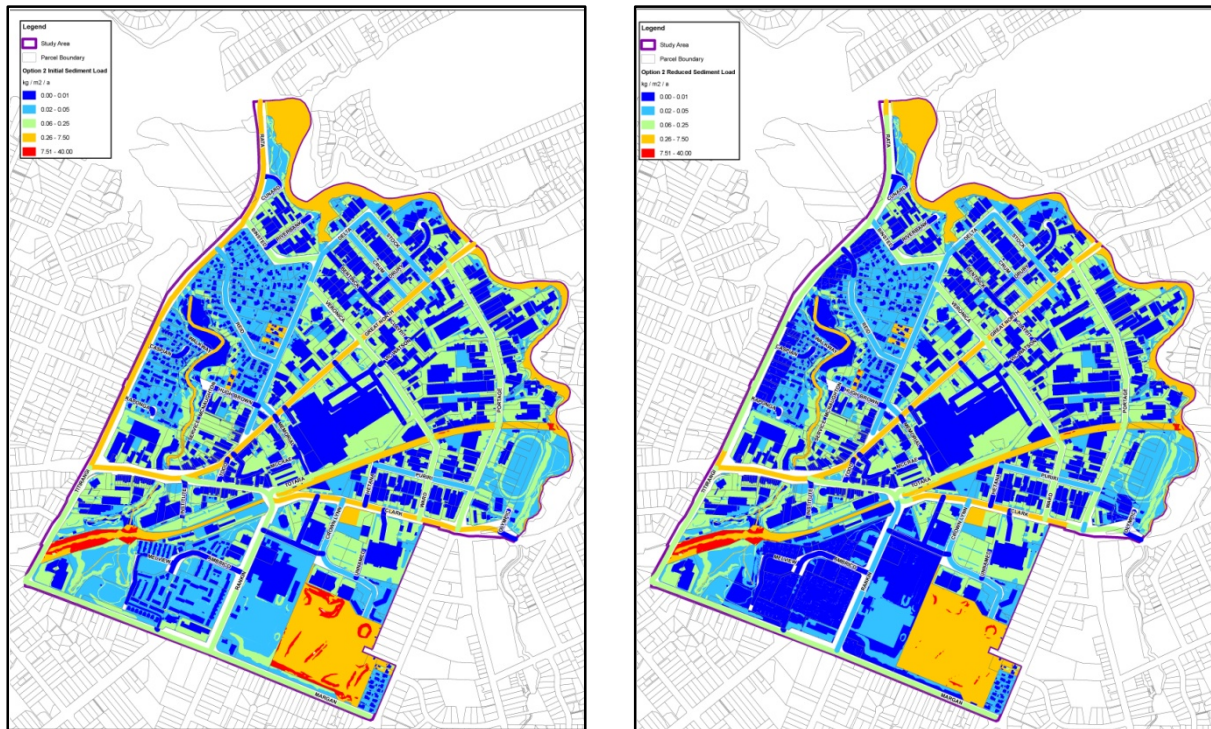A summary of results for each option is presented in Table 4.

Figure 5: Option 2 – Initial and Reduced Sediment Loads

Table 4: Summary of the NPS loadings Options 1 to 3

Option 1 - Current Status

Source Type	Area	Area Variance Vs Option 1	Sediment Initial	Sediment Reduced	Sediment Variance	Zinc Initial	Zinc Reduced	Zink Variance	Copper Initial	Copper Reduced	Copper Variance	TPH Initial	TPH Reduced	TPH Variance
	m2	m3	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum
Road	263,677	-	33,360	26,094	7,266	120	104	16	39	32	7	598	531	68
Roofs	364,303	-	1,890	1,701	189	241	238	2	0	0	0	-	-	-
Paved Surfaces Commercial	290,206	-	29,021	27,871	1,150	15	14	0	15	14	0	-	-	-
Paved Surfaces Industrial	16,876	-	844	194	650	2	0.8	1	2	1	2	-	-	-
Paved Surfaces Residential	39,290	-	786	506	280	3	2.1	1	0	0	0	-	-	-
Urban Grass lands	376,234	-	16,270	11,321	4,949	-	-	-	-	-		-	-	-
Urban Stream Channel	54,116	-	324,698	324,698	-	-	-	-	-	-		-	-	-
Construction Site 6 months	6,025	-	8,122	8,122	-	-	-	-	-	-		-	-	-
Construction Site 12 months	32,343	-	278,181	271,099	7,083	-	-	-	-	-		-	-	-
Stable Bush	29,838	-	1,114	1,114	-	-	-	-	-	-		-	-	-
SUM	1,472,907	-	694,285	672,718	21,567	379	359	20	56	48	9	598	531	68

Option 2 - Future 1

Source Type	Area	Area Variance Vs Option 1	Sediment Initial	Sediment Reduced	Sediment Variance	Zinc Initial	Zinc Reduced	Zink Variance	Copper Initial	Copper Reduced	Copper Variance	TPH Initial	TPH Reduced	TPH Variance
	m2	m3	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum
Road	263,677	-	33,360	26,094	7,266	120	104	16	39	32	7	598	531	68
Roofs	364,303	-	1,890	1,701	189	241	238	2	0	0	0	-	-	-
Paved Surfaces Commercial	290,206	-	29,021	27,871	1,150	15	14	0	15	14	0	-	-	-
Paved Surfaces Industrial	16,876	-	844	194	650	2	1	1	2	1	2	-	-	-
Paved Surfaces Residential	39,290	-	786	506	280	3	2	1	0	0	0	-	-	-
Urban Grass lands	309,344	- 66,890	13,335	10,634	2,701	-	-	-	-	-	-	-	-	-
Urban Stream Channel	54,116	-	324,698	324,698	-	-	-	-	-	-	-	-	-	-
Construction Site 6 months	6,025	-	8,122	8,122	-	-	-	-	-	-	-	-	-	-
Construction Site 12 months	99,233	66,890	614,040	349,190	264,850	-	-	-	-	-	-	-	-	-
Stable Bush	29,838	-	1,114	1,114	-	-	-	-	-	-	-	-	-	-
SUM	1,472,907	-	1,027,209	750,123	277,086	379	359	20	56	48	9	598	531	68
Variance Option 1 (O2-O1)	-	-	332,924	77,405	255,519	-	-	-	-	-	-	-	-	-

Option 3 - Future 2

Source Type	Area	Area Variance Vs Option 1	Sediment Initial	Sediment Reduced	Sediment Variance	Zinc Initial	Zinc Reduced	Zink Variance	Copper Initial	Copper Reduced	Copper Variance	TPH Initial	TPH Reduced	TPH Variance
	m2	m3	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum	kg/annum
Road	263,677	-	33,360	26,094	7,266	120	104	16	39	32	7	598	531	68
Roofs	397,793	33,490	2,058	1,701	357	246	243	3	0	0	0	-	-	-
Paved Surfaces Commercial	290,206	-	29,021	27,871	1,150	15	14	0	15	14	0	-	-	-
Paved Surfaces Industrial	16,876	-	844	194	650	2	1	1	2	1	2	-	-	-
Paved Surfaces Residential	49,352	10,063	987	552	435	3	3	1	0	0	0	-	-	-
Urban Grass lands	332,681	- 43,553	14,395	10,890	3,506	-	-	-	-	-	-	-	-	-
Urban Stream Channel	54,116	-	324,698	324,698	-	-	-	-	-	-	-	-	-	-
Construction Site 6 months	6,025	-	8,122	8,122	-	-	-	-	-	-	-	-	-	-
Construction Site 12 months	32,343	-	278,181	271,099	7,083	-	-	-	-	-	-	-	-	-
Stable Bush	29,838	-	1,114	1,114	-	-	-	-	-	-	-	-	-	-
SUM	1,472,907	-	692,779	672,333	20,446	385	364	21	56	48	9	598	531	68
Variance Option 1 (O3-O1)	-	-	- 1,506	- 385	- 1,121	6	5	1	-	-	-	-	-	-

6. COMMENTS

6.1 GEOSPATIAL APPROACH

Preparation of the input data is critical to ensure that the data sets are consistent and of good quality. However, an optimised approach for data acquisition and preparation in terms of accuracy and costs should be undertaken.

As an example, in this study, determining the roof type was one of the most challenging parts of data preparation. The roof types were determined on the basis of visual inspection by close observation on site or using binoculars where access was unavailable. Approximately 40% of the roofs within the study area were inspected and extrapolated to the roofs that were not inspected. Other factors were estimated for each property by usingaerial imagery and the year of construction. It is considered that for the purpose of this analysis the approach is sufficient. However, if the goal is to achieve greater certainty (e.g. for legal or rating objectives) regular inspections involving access onto the roofs and a reliable record keeping processes would be required to get accurate information.

A map showing roof materials is represented in Figure 6.
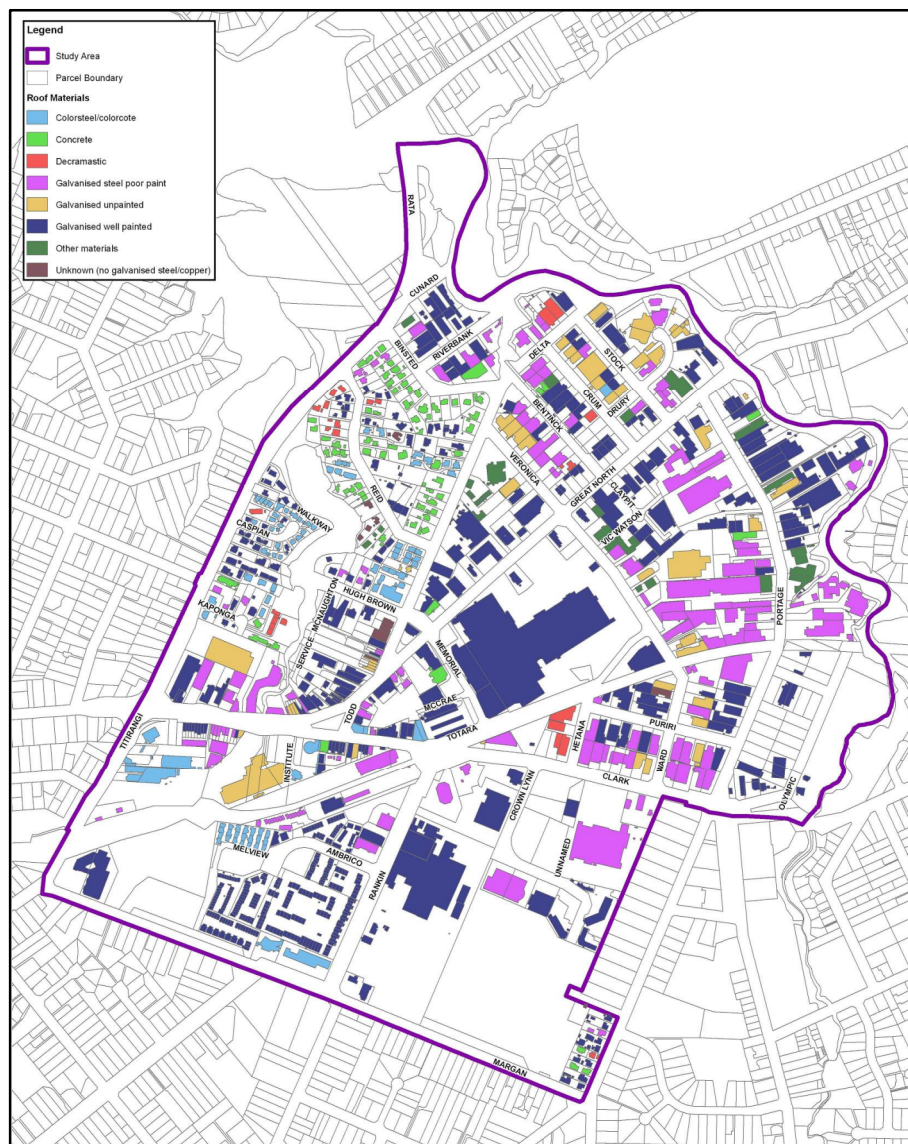

Figure 6: Roof Materials

6.2 OUTPUTS

The following discussion is focused on some of the key outputs relevant to the approach rather than environmental considerations.

The key outputs from the assessment are presented as follows:

- A comprehensive spatial database that contains required inputs for NPS pollution analysis including land use, contaminant yield values, reduction efficiency values, impervious areas, roads etc. This database can be used interactively for further analysis of preferences for stormwater treatment options.
- The same database contains calculated contaminant loads for Options 1 to 3.
- Contaminant yields and reduction factors database.
- Maps visualising CLM results per each NPS type area and normalised loads for each source expressed in kg/area/annum (e.g. Option 2 Sediment loads as shown in Figure 5).
- Summary of the NPS loadings in table format for Options 1 to 3.
- Table with cost estimates for treatment provisions per NPS contaminant.
- Kml (GoogleEarth file format) files representing CLM results.

In addition there are other outputs noted as follows:

The total study area is 147 ha. The total suspended solids load for Option 1 is 694 tonnes / annum where most of the load comes from the urban stream channels (48 %) and construction sites (40 %). The results are biased towards those source types because the CLM rates appear to be highest for that group. Refer to Figure 7 below.
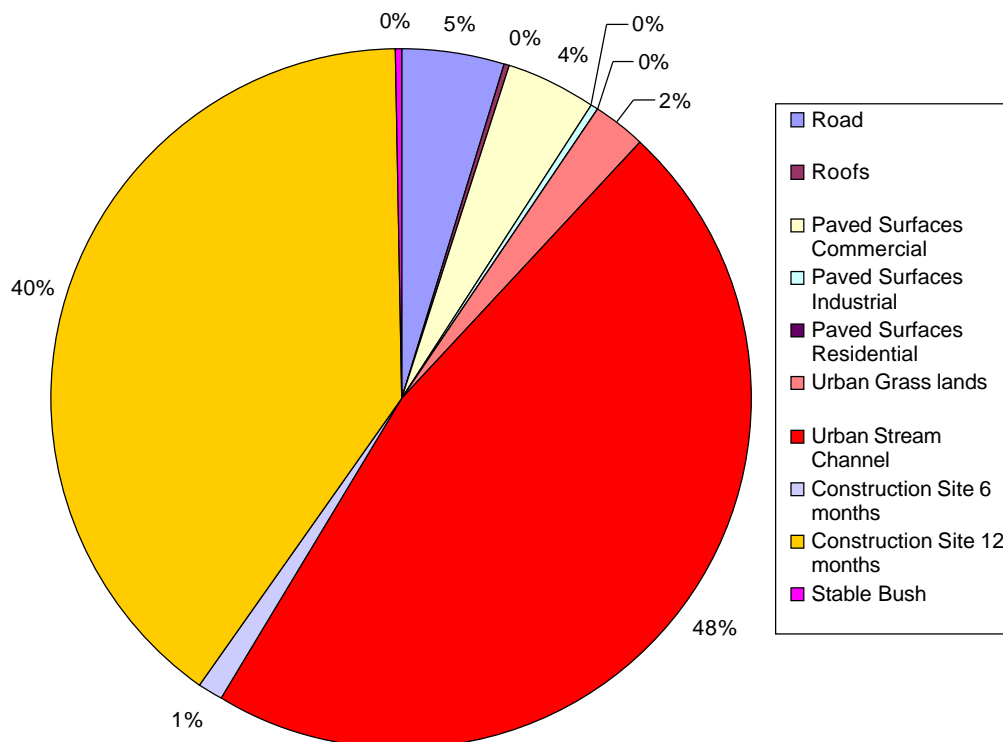
Figure 7: Suspended Solids Loadings Option 1

Sensitivity of the changes of source type inputs (land use changes) has been tested through option 1 to 3 and also factoring in the reduction rates achieved by the existing treatment devices. A summary of the loadings (Table 4) suggests that the most significant changes are related to the suspended solids. This is because the difference in CLM loadings is significant. There were no significant changes noted with heavy metals.

The authors have also normalised the outputs and so that yield rate assigned back to each discrete area is defined by a polygon of a particular source type. This gives in return the ability to visualise where the pollution is coming from and to prioritise a treatment response on a spatial basis.

The outputs can be used as an aid to choose the future treatment locations and cost estimates on an area wide basis. Current treatment catchments and devices are shown in Figure 8. The currently serviced area is approximately 34 ha. The total treatable area is approximately 101 ha. This is calculated as a total study area of 147 ha less bush, stream and urban grass area of 46 ha. Thus the remaining area to be treated is 67 ha multiplied by treatment cost $ 70,535 /ha equals $ 4.7 million for implementing stormwater treatment within the study area. The rate is adopted from the New Lynn LID Feasibility Study 2009.
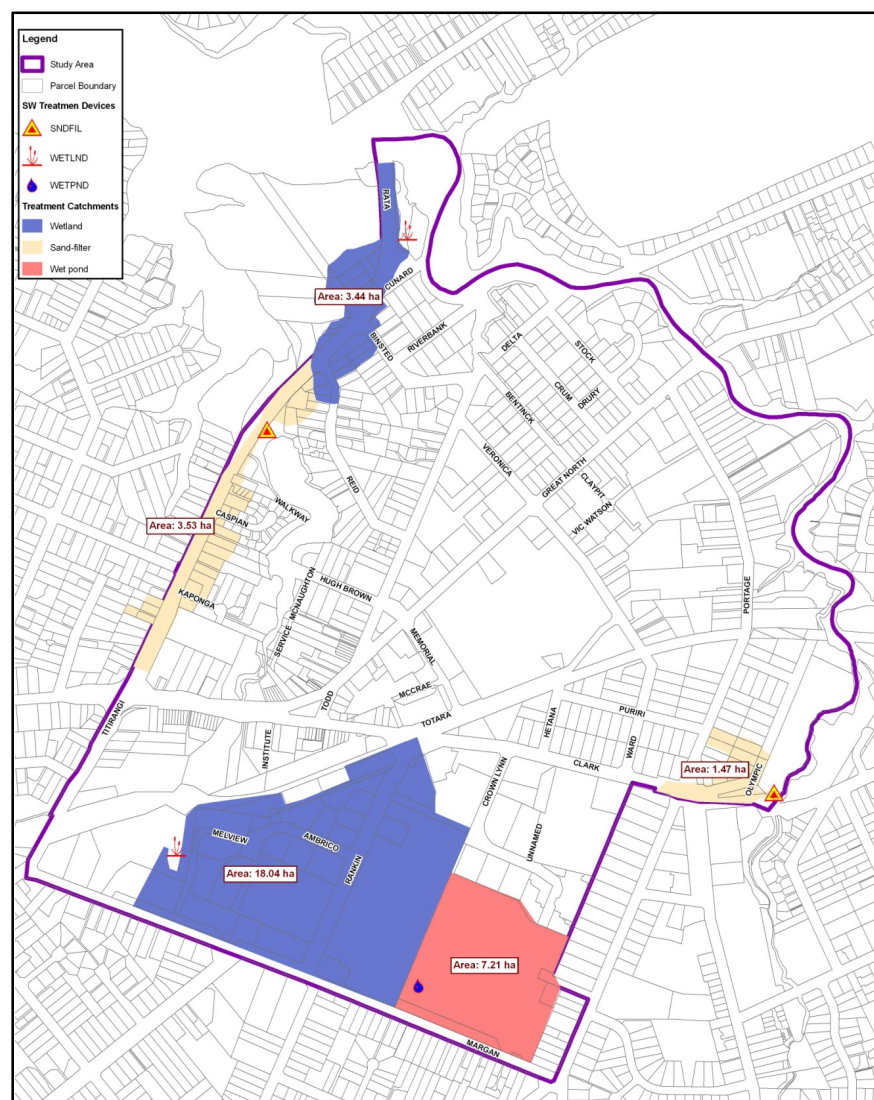

Figure 8: Current treatment catchments and devices

7. CONCLUSIONS

The Spatial Approach developed for assessment of contaminant loads in stormwater runoff is a useable, reliable and repeatable means of establishing NPS pollution estimates in stormwater runoff. The principal benefit of spatial analysis approach is that the models can deal with large volumes of spatial data that geographically locate and identify many environmental processes (Corwin, 2006).

Spatial datasets of good quality are readily available from Council's GIS database for input into spatial models.

Spatial analysis and models offer the advantage over the existing spreadsheet approach as their approach combines existing and acquired geo spatial and non-spatial data onto a single IT platform, thus enabling strategic decision making for catchment management.

This pilot study demonstrates that the spatial approach provides insights into the generation of pollutants within the study area and in turn supports the decision-making process in preparing and optimising responses. The key aspects to consider in applying the spatial approach to NPS analysis are:

- Leveraging on systems and procedures that are already in existence in other activity areas of the Council and adjusting them where necessary for the specific purpose of NPS analysis.
- Collaboration between key stakeholders, departments as well as individual practitioners.
- Building up organisational capabilities in spatial science and providing for innovation and learning.

In conclusion the spatial approach has great potential to be used in exploring and resolving complex relationships in environmental engineering and science. The NPS assessment is an area where it can be used efficiently in analysis of effects, service demand, asset management, priorities and optimised decision making processes.

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