SPATIAL FRAMEWORK FOR STORAGE AND ANALYSES OF FISH HABITAT DATA IN GREAT LAKES' AREAS OF CONCERN: HAMILTON HARBOUR GEODATABASE CASE STUDY

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ABSTRACT

Doolittle, A.G., Bakelaar, C.N., and Doka, S.E. 2010. Spatial framework for storage and analyses of fish habitat data in Great Lakes' Areas of Concern: Hamilton Harbour geodatabase case study. Can. Tech. Rep. Fish. Aquat. Sci. 2879: xi + 68 p.

A spatial framework approach for storage and analyses of fish habitat data has been used to compile physical fish habitat data into a geographic information system (GIS). This approach synthesizes data from different projects into a geographic database (geodatabase), it can be utilized as a guide in standardizing formats, data structures and data layers that are used in generating and mapping key habitat features (vegetation, substrate, depth). These layers support fish habitat suitability, habitat supply, fish population and ecosystem models. Difficulties encountered will be discussed as well as rationale for the approach used. Construction and storage of these spatial layers within a GIS enables quantitative measurements of habitat and analysis of trends over time and space.

Hamilton Harbour (Lake Ontario) has been identified as a Great Lakes' Area of Concern (AOC) signifying that its ability to support aquatic life has been impaired. Contributing to the effort to restore this degraded area is in concert with Fisheries & Oceans Canada's (DFO) commitment to healthy and productive ecosystems in Canada. In 1989, DFO's Great Lakes Laboratory for Fisheries and Aquatic Sciences (GLLFAS) began a number of projects to assess the current state of Hamilton Harbour. Together, they will assess progress toward Remedial Action Plan (RAP) targets for fish habitat and populations of phytoplankton, zooplankton, benthos and fish, and evaluate the ability of the ecosystem to meet all of the RAP's targets.

Parallels can be drawn from the Hamilton Harbour Area of Concern case study to DFO's "place-based" management goals in the Great Lakes because it uses a science-based approach to identify the spatial influence of factors that contribute to ecosystem health. Incorporating scientific, biological and physical information into a geodatabase/GIS is one method in which data can be synthesised and visualized; thus, decisions can be based on closer integration among professionals who strive to manage our damaged ecosystems.

RÉSUMÉ

Doolittle, A.G., Bakelaar, C.N., and Doka, S.E. 2010. Spatial framework for storage and analyses of fish habitat data in Great Lakes' Areas of Concern: Hamilton Harbour geodatabase case study. Can. Tech. Rep. Fish. Aquat. Sci. 2879: xi + 68 p.

Nous avons utilisé un cadre spatial pour le stockage et l’analyse des données relatives à l’habitat du poisson afin de compiler des données physiques dans un système d’information géographique (SIG). Cette approche fait la synthèse des données de différents projets dans une base de données géographiques. Elle peut aussi servir de guide quant à la normalisation des formats, des structures et des couches de données qui sont utilisés pour la création et la cartographie des caractéristiques essentielles de l’habitat (végétation, substrat, profondeur). Ces couches de données seront utiles en ce qui a trait à la qualité de l’habitat, les reserves de l’habitat, la population des poissons et aux modèles d’écosystème. De plus, l’établissement et le stockage de ces couches spatiales dans un SIG rendent possibles les mesures quantitatives de l’habitat et l’analyse des tendances spatio-temporelles. Par ailleurs, il sera question des difficultés rencontrées ainsi que de la justification scientifique de l’approche utilisée.

Le havre Hamilton (lac Ontario) a été désigné comme secteur préoccupant (SP) des Grands Lacs, ce qui signifie que sa capacité de servir d’habitat aux organismes aquatiques s’est vue réduite. L’effort en vue de restaurer cette zone détériorée s’inscrit dans la foulée de l’engagement pris par le ministère des Pêches et des Océans (MPO) relativement au maintien d’écosystèmes sains et productifs au Canada. En 1989, le Laboratoire des Grands Lacs pour les pêches et les sciences aquatiques (LGLPSA) du MPO a lancé plusieurs projets pour évaluer l’état actuel du havre Hamilton. Ensemble, les deux entités mesureront les progrès accomplis par rapport aux objectifs du plan d’assainissement (PA) pour l’habitat du poisson et les populations de phytoplancton, de zooplancton, de benthos et de poissons, et elles évalueront la capacité de l’écosystème à atteindre tous les objectifs du PA.

Des parallèles peuvent être établis entre l’étude de cas du secteur préoccupant du havre Hamilton et les objectifs de la gestion « axée sur le milieu » du MPO pour les Grands Lacs, puisqu’une approche scientifique est utilisée pour déterminer l’influence spatiale des facteurs qui contribuent à la santé de l’écosystème. Incorporer de l’information scientifique, biologique et physique dans un SIG est une méthode grâce à laquelle les données peuvent être synthétisées et visualisées; ainsi, les décisions peuvent s’appuyer sur une intégration plus étroite parmi les professionnels qui s’efforcent de gérer nos écosystèmes endommagés.

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1.0 INTRODUCTION

Located on the west end of Lake Ontario, Hamilton Harbour is situated between the city of Hamilton (primarily to the south) and the city of Burlington (north) (Figure 1).

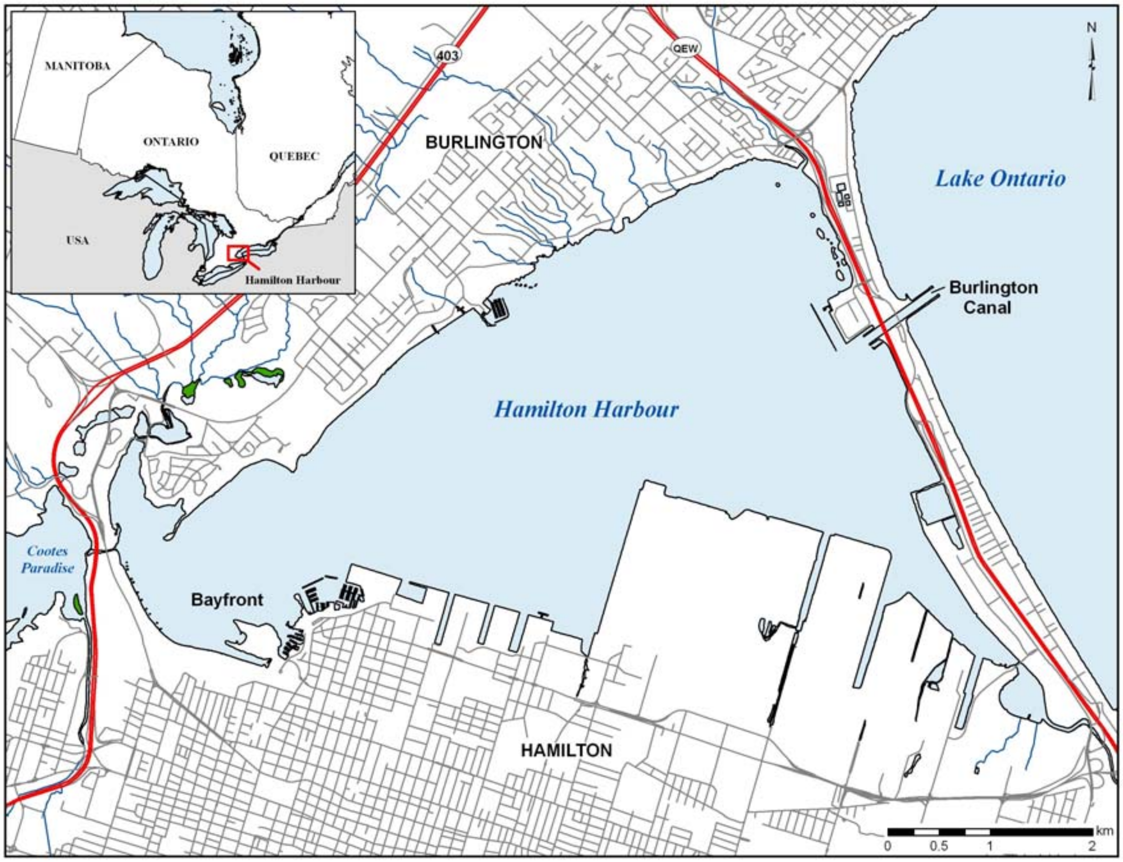

Figure 1. Hamilton Harbour, Lake Ontario, Canada.

The harbour is an important hub for shipping activities through the Burlington canal, primarily for industries along the southeast shoreline in Hamilton. The north shore in Burlington is mainly residential with mixed recreational use to the west. Recreational boating is a popular activity in the harbour, supported by various marinas along the north shore and south west in and around the Bayfront area. Residents in the area can enjoy hiking trails, powered and non-powered watersports, fishing, beaches and cultural activities, including restaurants, museums, parks and festivals.

Over 200 years of history, the harbour encountered a significant amount of habitat destruction and pollution. According to the Bay Area Restoration Council (BARC), "By 1926, canals and infill eliminated more than two-thirds of the original wetlands, protected inlets and shallow areas. By the early 1900s, the harbour ecosystem was severely degraded as a result of direct sewage discharges, habitat loss, toxic spills and sediment contamination." (BARC 2008). Recognizing the need for change, in 1987 the International Joint Commission (IJC) designated Hamilton Harbour as an "Area of Concern" (AOC), one of 43 areas identified in the Great Lakes Basin. As such, the harbour is recognized as having at least one or more of the 14 use impairments identified for AOCs (Ontario Ministry of Environment and Environment Canada 1992).

Table 1. Use impairments.

I.	Restrictions on fish and wildlife consumption
II.	Tainting of fish and wildlife flavour
III.	Degraded fish and wildlife populations
IV.	Fish tumours or other deformities
V.	Bird or animal deformities or reproductive problems
VI.	Degradation of benthos
VII.	Restrictions on dredging activities
VIII.	Eutrophication or undesirable algae
IX.	Restrictions on drinking water consumption or taste or odor problems
X.	Beach closings
XI.	Degradation of aesthetics
XII.	Added costs to agriculture or industry
XIII.	Degradation of phytoplankton and zooplankton populations
XIV.	Loss of fish and wildlife habitat

In 1992, a Remedial Action Plan (RAP) for Hamilton Harbour was established. This plan offered various recommendations to improve water quality and environmental conditions for humans and other biota. As a member of the Bay Area Implementation Team (BAIT), Fisheries and Oceans Canada (DFO) has assisted in the coordination and implementation of remedial actions required in an effort to delist Hamilton Harbour as an AOC. This support includes research and expert advice, and addresses a number of use impairments listed above.

As indicated in a report by Minns et al. (2006), "The health of fish communities, and their dependent fisheries, is a key indicator of ecosystem health." The goal of this document is to explain how spatial data was collected and compiled in a Geographic Information System (GIS) to support research related to habitat requirements of healthy fish populations. The development of a data framework for spatial information serves as a geodatabase in which data is stored, processed and retrieved, and as a key metadata tool.

1.1 SPATIAL DATA FRAMEWORK FOR FISH HABITAT INFORMATION

The primary driver behind a spatial data framework for fish habitat information is the ability to store, integrate and process habitat data required and collected by DFO researchers for further analysis and modeling in the harbour. Key habitat features are mapped such as macrophyte distributions, substrate composition and depth, and then applied in fish habitat supply analysis (HSA), population and ecosystem modeling. A number of factors driving the development of the spatial data framework include:

* Organization (of compiled, collected and partner data)
* Coordination (of data that is supplied by and used by more than one project)

* Filling data gaps (identification of spatial data gaps)
* Integration and standardization (between projects and across AOCs)
* Ease of use (facilitate the process of querying, extracting and sharing data).

This spatial data framework, structured within a geodatabase, will serve as a common storage and management framework for geographic information and spatial data for DFO science. It includes geographic features, associated attribute tables, point and transect field information as well as remotely sensed acoustic, satellite and aerial imagery.

1.2 THE GEODATABASE

A "geodatabase" is a geographic database that has the capability of storing spatial layers and attribute data in a relational database management system (RDBMS). A geodatabase can be simple or complex, but largely depends on the nature of its application. There are many advantages of utilizing a geodatabase for storing spatial data, a few are listed below:

- Store a rich collection of spatial data in a centralized location (facilitates data access and maintenance).
- Apply sophisticated rules and relationships to the data (e.g. sample locations must fall within shorelines).
- Define advanced geospatial relational models (e.g. topologies, networks).
- Maintain integrity of spatial data with a consistent, accurate database.
- Integrate spatial data with other IT databases.
- Support custom features and behaviour through programming, scripts and data models (ESRI 2010a).

The geodatabase stores a variety of data "objects", in many different formats. The following table represents a sample of supported objects (ESRI 2010b).

Table 2. ESRI supported data objects.

Object	**Description**
Tables	non-spatial objects or descriptive information
Feature Classes	spatial features, such as points, lines or polygons
Feature Datasets	containers for feature classes that share the same spatial reference
Relationship Classes	manage thematic relationships between tables/feature classes/both
Geometric Networks	used in flow network analysis – relationships between point and line features
Topologies	spatial relationships within and between feature classes – used to find and fix spatial errors
Raster Datasets	gridded data derived from various formats (.img, .jpg, interpolations, etc.)
Raster Catalogs	tables that reference a collection of raster image files
Survey Datasets	store survey information and can group survey data into projects, and multiple projects into a project folder
Toolboxes	geoprocessing tools used in the ArcGIS geoprocessing framework
Behaviour Rules	define legal or permitted attribute values, relationships between classes, topological relationships between features, and connections between network features

In addition to the above, a geodatabase supports a variety of spatial modeling, data management and analysis functions. One of the key benefits is that the implementation of data structures and validation rules allows users to model reality more closely than was possible with other data models (ESRI 2004). This approach to modeling benefits the analysts who manage and manipulate the data directly, and also the scientists who develop fish habitat and population models. Certain approaches and data structures were adapted from the Marine Data Model, developed by ESRI and the marine GIS community. This model assists in the organization and maintenance of data within DFO, and supports modeling and management decisions related to habitat and biota including water quality.

Commonly known as “Arc Marine”, users in the marine GIS community have worked to establish a model that supports applications in oceans and coastal areas. This community, including academic, government and non-government organizations and researchers, required a database design that facilitated the collection of dynamic and multidimensional data from the oceans, seas and coasts. It also strived to provide a more logical way to represent these data in the object-oriented world of the geodatabase (Wright 2007).

As a result, the Marine Data Model or framework assists users with data input, storage, and dissemination of data using a pre-configured geodatabase template. It can also assist in improving performance with data processing (particularly with larger datasets, such as bathymetry) and analysis of this data (e.g. time series, coastal processes, etc.). Wright (2007) indicates that the data model improves the ability to manage and exchange large marine datasets using a framework that can be shared and implemented across many platforms and applications.

The same benefits have driven the development of a DFO fish habitat data model that could be applied to AOCs. DFO Science has been working with other organizations to improve conditions in areas such as Hamilton Harbour, Bay of Quinte, and the Detroit and St. Clair Rivers in the Huron–Erie Corridor (HEC), in an effort to delist them as Areas of Concern. A common data model was a logical step in the planning process, particularly because each AOC has common delisting targets, sampling protocols, and data needs, such as fish habitat information gathering. Much of this document will focus on the Hamilton Harbour fish habitat data model and resulting geodatabase. The concepts, methods, and applications can be applied to other areas providing the appropriate data exists and that the relationships and data structure provide the desired results.

1.3 THE STAGES OF GEODATABASE DEVELOPMENT

The development of a geodatabase can be conceptualized as a four-step process: (1) the design stage, (2) the input stage, (3) the test stage, and (4) the implementation stage (Figure 2).

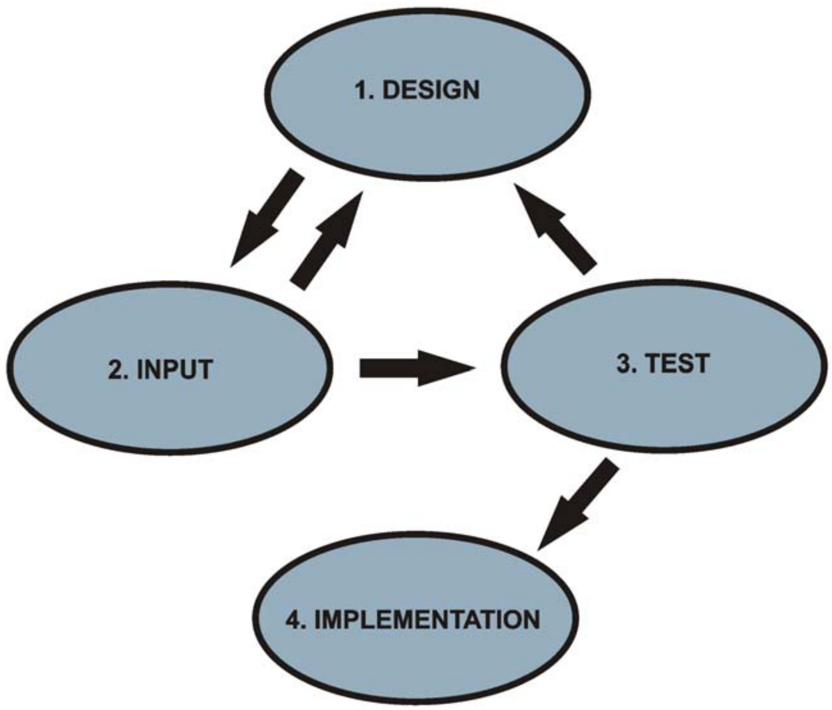

Figure 2. Geodatabase stages of development.

This is an iterative process that may require adjustments at each stage to ensure all project requirements are met.

1. THE DESIGN STAGE

The design stage is important because it identifies data types collected and required by researchers. It allows the data manager and scientist to scope additional data needs and manage expectations based on resources. Often adaptation of the design is necessary to achieve the desired end-user application, as in our study (e.g. web mapping). Establishing a flow diagram or conceptual model of the design can be valuable in documenting needs and examining relationships between the spatial layers and their attributes. Documenting how information will be used is a prerequisite, particularly with complex modeling. It is important to structure data in a way that facilitates the mathematical modeling process, recognizing that information may be processed directly within a GIS or summarized for use in an external model. Having the ability to link information back to features is important, and must be addressed in the design stage.

2. THE INPUT STAGE

The input stage often represents the bulk effort of a project as it requires a significant amount of time with the input and management of data. Data collected or acquired from different sources may not fit into the standardized data model framework. Depending upon the location of a project, it may be necessary to establish a common spatial coordinate system in order to align data. Identification of data gaps may require further research into different data sources or methods that could be used to generalize and represent the dataset as a whole (through interpolation), or may even require a revisit to the design stage to address these concerns.

3. THE TESTING STAGE

The testing stage provides an opportunity to query, extract, and report on the data, identifying whether or not all user requirements have been met. A revisit to the design stage will be required if they are not.

4. THE IMPLEMENTATION STAGE

The implementation stage represents the final goal of the project. Data is consolidated, modeling (both mathematical and spatial) is complete, and results have been generated through mapping and/or reporting on methods used in the spatial analysis.

The foundation for the fish habitat geodatabase model lies within the design or conceptual model stage, and are examined in greater detail below.

2.0 PURPOSE AND OBJECTIVES

The main objective of this project was to create and store spatial data layers that will be used by DFO researchers in support of fish habitat suitability, supply and population modeling (Doka et al., unpublished data). The goal of this report is to document the stages of development used in the Hamilton Harbour geodatabase. It explores, in detail, the methods required to create fish habitat layers, the fish habitat geodatabase model, and the range of data required by DFO researchers to make decisions and recommendations on remedial actions within the Hamilton Harbour AOC.

3.0 METHODS

3.1 HAMILTON HARBOUR GEODATABASE STAGE 1: DESIGN

The design stage is important because it identifies information required to accomplish certain tasks or achieve certain goals. Visually, this can be achieved with a conceptual model diagram or a data flow diagram. A conceptual model is a tool that bridges the gap between a graphical representation of a process and a computer data processing model. A GIS has been used to model and manage both tabular and spatial data in a geographic database (geodatabase). Each object in the diagram represents an object in the geodatabase that is required or necessary to create the final spatial layers for visualization and future simulation modeling. Each object may have a relationship to an attribute table (providing more detailed information about the object) or may have a relationship to another object. For example, survey transect data may be represented as a sample point (Object A). A sample point has a defined relationship to the transect layer (Object B) and to an attribute table. A relationship between the point layer and the survey transect layer provides the user with information about the transect via a data model (Figure 3).

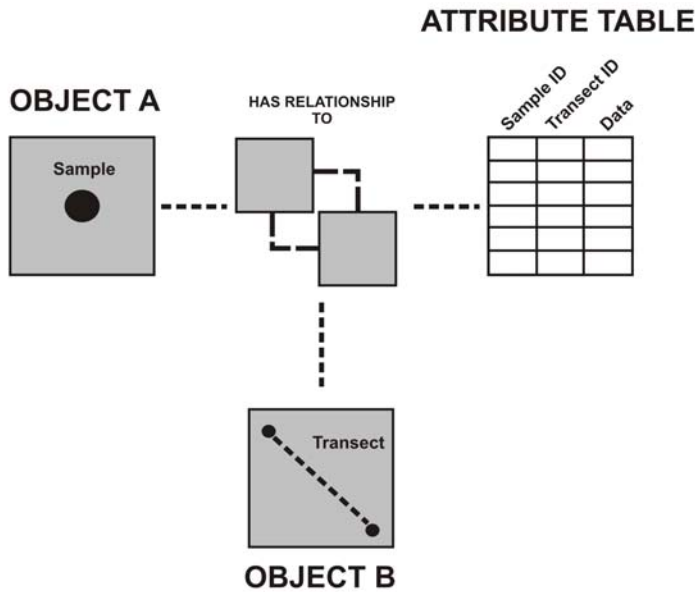

Figure 3. Simple relationship between spatial and tabular information.

Tabular data can be extracted through queries based on key relationship identifiers (primary key), or unique IDs. Therefore, a sample point sharing a common ID with a sample transect allows a user to draw the same information from the tabular data.

Relationships can be simple or complex in nature. Complexity reflects the nature of the project, the available data that is used in the analysis, and the number of variables needed to identify patterns and relationships in the spatial data for the area of interest. The Hamilton Harbour data model relies heavily upon a grid format to store information and perform various spatial analyses. To simplify this concept, the harbour is represented on a map as evenly spaced grid cells, and for the purpose of this case study, uses a 5 m x 5 m cell size. Unlike traditional cartographic symbols such as points, lines and polygons, habitat features are related or spatially associated in a series of overlapping grids. If each grid was merged together, and each cell was converted into a point (at the centroid of each cell), each point would have a number of habitat variables associated to it that would feed into a model that would help classify each individual grid cell or point as low, medium or high suitability (Figure 4).

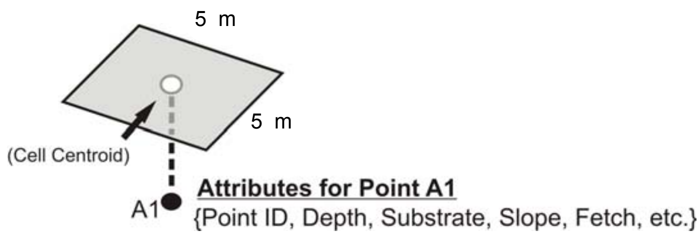

Figure 4. Conceptual grid cell attributes.

There are a number of advantages of storing information as a grid:

- A simple data structure—A matrix of cells with values representing a coordinate and sometimes linked to an attribute table
- A powerful format for advanced spatial and statistical analysis
- Has the ability to represent continuous surfaces and to perform surface analysis
- Has the ability to uniformly store points, lines, polygons, and surfaces
- Has the ability to perform fast overlays with complex datasets (ESRI 2010c).

The design stage is fundamental in identifying layers and information needed to accomplish the spatial analysis objectives. Completion of this stage facilitates the transition into the second stage, data input.

3.2 HAMILTON HARBOUR GEODATABASE STAGE 2: INPUT

DFO researchers required a number of key datasets in order to complete the classification and analysis of fish habitat in Hamilton Harbour. These datasets were physical, chemical or biological in nature. Each is regarded as a key component of fish habitat, indicating the overall health of aquatic habitats (Minns et al. 2006). Data input for these geodatabase layers required 1) assembly and synthesis of data (e.g. emergent and submergent vegetation, depth, substrate, and toxicity) and 2) tabulating the layers for use in habitat suitability modeling used to classify the habitat of the study area depending on fish usage. Data sources for the Hamilton Harbour geodatabase can be found in Table 3.

Table 3. Primary data sources for the Hamilton Harbour geodatabase.

Description	Organization	Contact	Time Period Data Collected
Bathymetry (single & multibeam)	CHS	A. Leyzack, T. Segal	2002 & 2005
Bathymetry	City of Hamilton, Public Works	J. Helka	2005
Shoreline Data	OMNR	K. Todd	2002
DEM	OMNR	K. Todd	2002
Navigational Chart (1915)	CHS	P. Travagliani	1915
Substrate sample points	EC - NWRI	Rukavina and Versteeg	1980s - 1990s
Zebra Mussel Samples	DFO - GLLFAS	R. Dermott	1984
Electrofishing Habitat Samples	DFO	C. Brousseau	1995
Habitat Sampling (ponar, shoreline, acoustics)	DFO	K. Leisti	2006/07
Restoration Sample Locations	HH RAP	J. Hall	Unknown
CAD Shoreline Data (classified)	OMNR	K. Todd	2002
Orthoimagery	Google Earth	Google Inc.	2007
Orthoimagery	OMNR	K. Todd	2002
Backscatter Data	DFO -CHS	A. Leyzack	2002 & 2005
Toxicity Sample Points	EC	D. Milani	2000 - 2006, 2010
Base Data Layers (multiple)	OMNR	LIO	Various
Vertical Benchmark Data	NRCAN	P. Sauvé	Unknown

CHS - Cahadian Hydrographic Service
DFO - Fisheries and Oceans Canada
EC - Environment Canada
GLLFAS - Great Lakes Laboratory for Fisheries and Aquatic Sciences
HH RAP - Hamilton Harbour Remedial Action Plan
NRCAN - Natural Resources Canada
NWRI - National Water Research Institute
OMNR - Ontario Ministry of Natural Resources

In reference to the Hamilton Harbour geodatabase model, this section will examine three types of data:

1. Base Data • data that can be used for general mapping, spatial reference

2. Sample Data • data that represents field collected sample information used to support spatial analysis

3. Modeled Data • base and sample data compiled and spatially modeled for fish habitat applications and analysis

Each component contributes to the input stage of geodatabase development. Information and data is compiled and layers are created that reflect the nature of the spatial phenomena or the format of the data structure needed for further modeling. A number of challenges can arise in this stage particularly when compiling a single modeled GIS layer from multiple data sources (e.g. substrate).

3.2.1 Base Data (Cartographic Layers)

Base data features represent layers in the data model that can be used as inputs for the simple layer generation, mapping, context, and even further analysis. Point layers in the base data include geographic features (for labeling maps or locating named features), and elevation points (including spot elevations, bathymetry points). Line features represent road networks, stream networks, contours and shorelines. Polygon features represent geographic boundaries (including townships, municipalities, etc.), watersheds, and waterbody polygons (e.g. permanent and intermittent). Orthoimagery and satellite imagery is valuable as a cartographic layer as it provides a snapshot picture of the study area – useful to compare temporally with other imagery, or to be used in interpretation or map display (Figure 5).

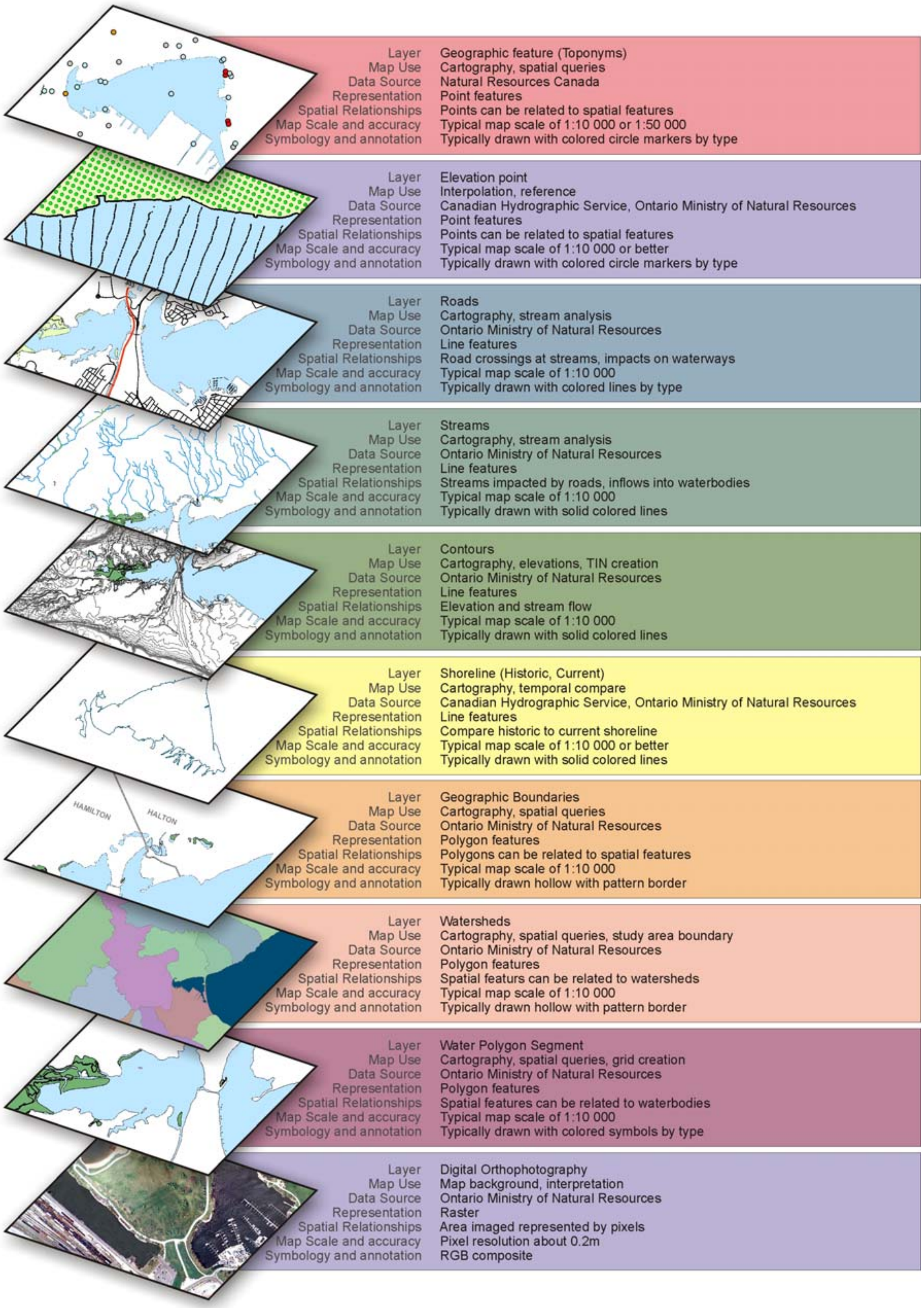

Figure 5. Example of base data used in the Hamilton Harbour geodatabase.

3.2.2 <u>Sample Data</u>

Sample data within the geodatabase supports layers used for modeling habitat, often represented as point or line (transect) locations (Figure 6).

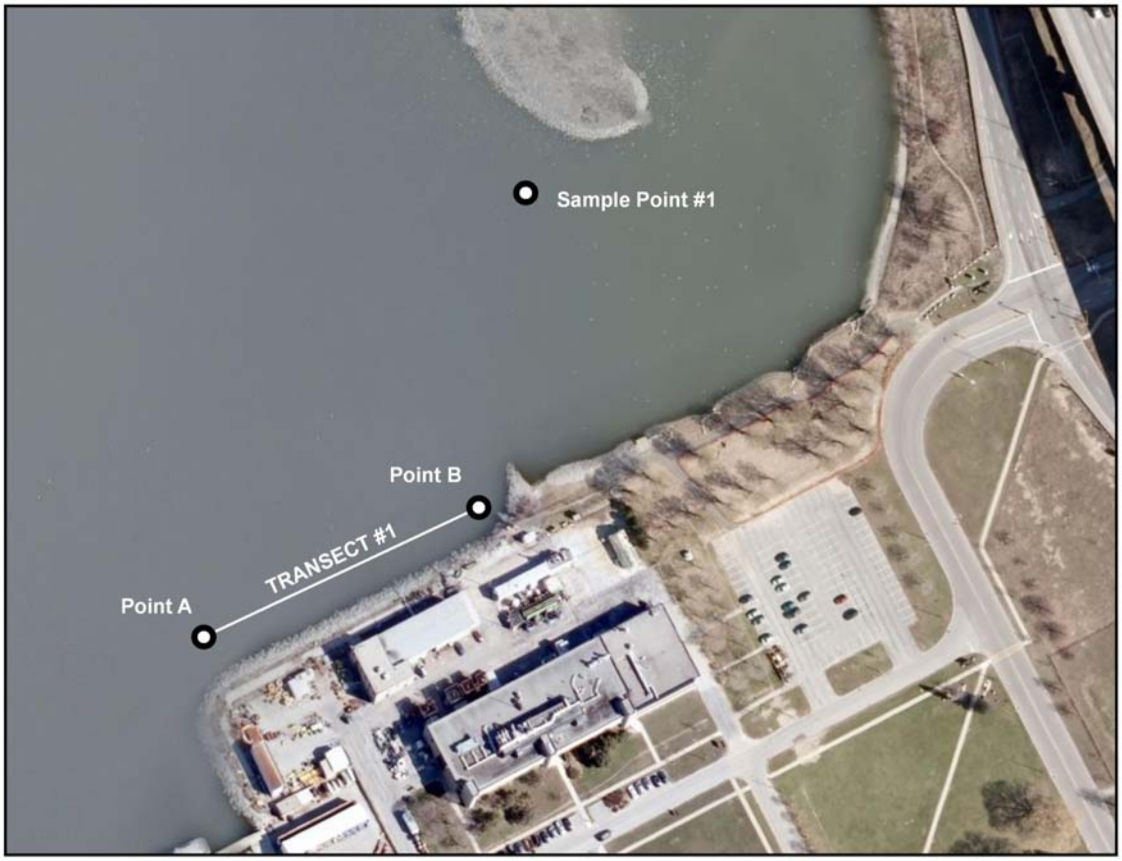

Figure 6. Example of sample points and lines (transects) stored in the Hamilton Harbour geodatabase.

Point sample data has been provided by various organizations including DFO, Environment Canada (EC), and other agencies that have sampled in the harbour. While not all data collected and stored is relevant or necessary to the habitat modeling, often information could be extracted or derived from the sample data to add value to one or many habitat model input layers (e.g. fish community interaction or Secchi values for submergent vegetation modeling). Examples of sample data types include fish species, zebra mussel abundance, zooplankton and phytoplankton density, benthic samples, emergent or submergent aquatic vegetation (SAV), substrate type, temperature profiles, dissolved oxygen concentration, toxicity sediment classes, substrate classes (using acoustics) and Secchi depth. This list is not static and additional variables or sample data could be incorporated into the dataset, if necessary. Temperature and dissolved oxygen profiles or time series are also collected by field crews in an effort to capture as much information about a sample location as needed to accurately reflect water quality and habitat conditions. Several in situ monitoring stations were set up across the harbour for extended periods to capture much needed temporal data or key limnological processes that may impact the fish habitat availability. All the series data have not been incorporated into the current geodatabase, but are being analysed for future incorporation of key time series elements (i.e. seasonal patterns).

Sample transect data, represented as linear geographic features (point A to point B), have also been incorporated into the geodatabase. DFO researchers have collected information including fish community data, macrophyte densities, temperatures taken at start/middle/end location, dissolved oxygen (same as temperature) and substrate (using acoustics). Much of this work is on-going, adding temporal information to the transect data (Figure 7).

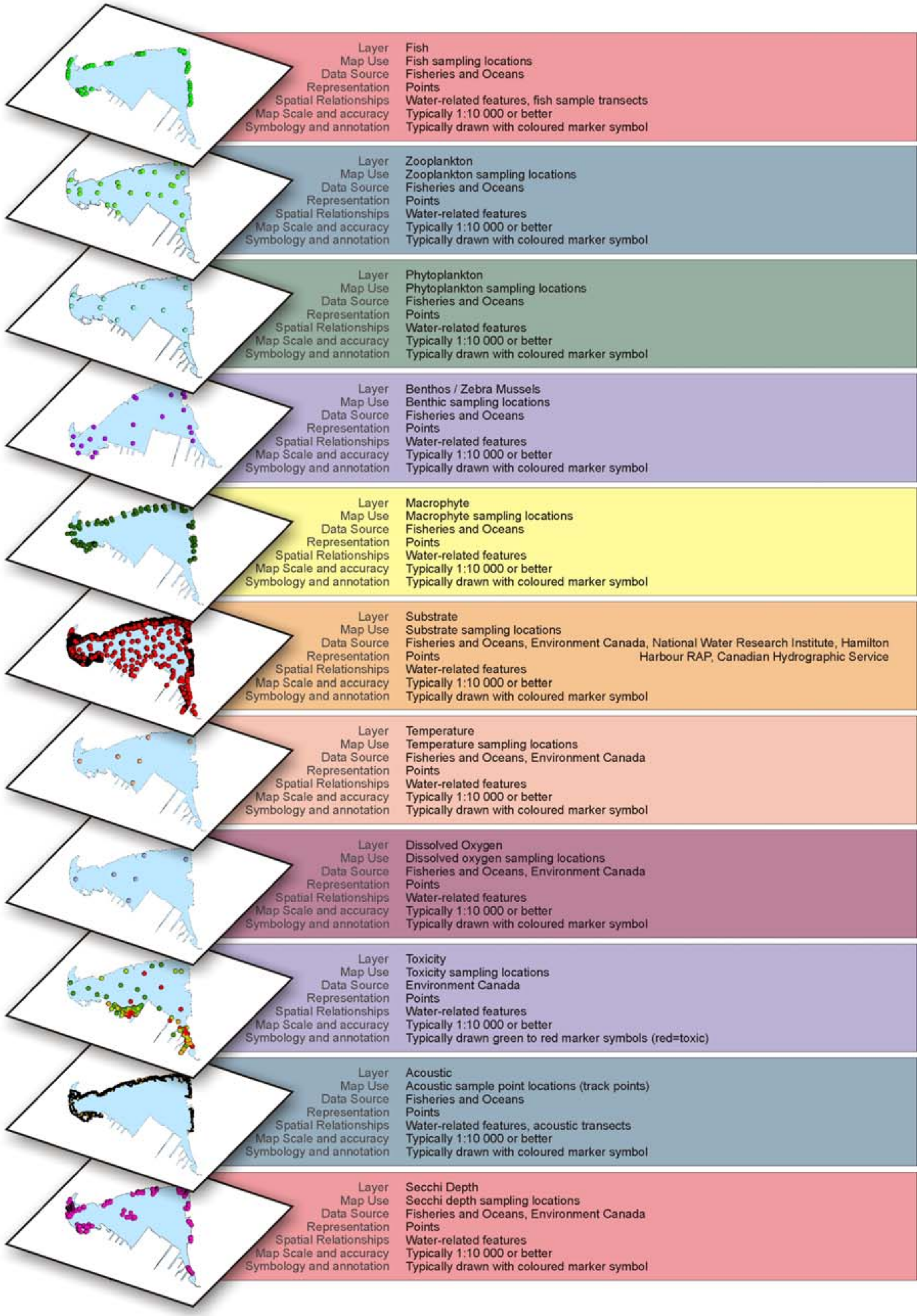

Figure 7. Example of field sample data used in the Hamilton Harbour geodatabase.

3.2.3 <u>Modeled Data</u>

Modeled data represents base and sample data that has been combined and manipulated to create layers required for fish habitat analysis and modeling. In reference to the fish habitat data framework, these modeling layers have been classified as either "simple" or "complex":

Simple:
- a single thematic layer or feature (e.g. depth)
- Can be complicated to assemble because it requires data and location-specific interpretation

Complex:
- a single thematic layer created by combining simple layers to produce a unique output (e.g. submergent aquatic vegetation)

  Or

- Integrated multiple spatial data layers with statistical models (e.g. Habitat Suitability Analysis)

Simple modeling layers include bathymetry (elevation), substrate, fetch, slope, turbidity, aquatic vegetation and toxic sediments (Figure 8).

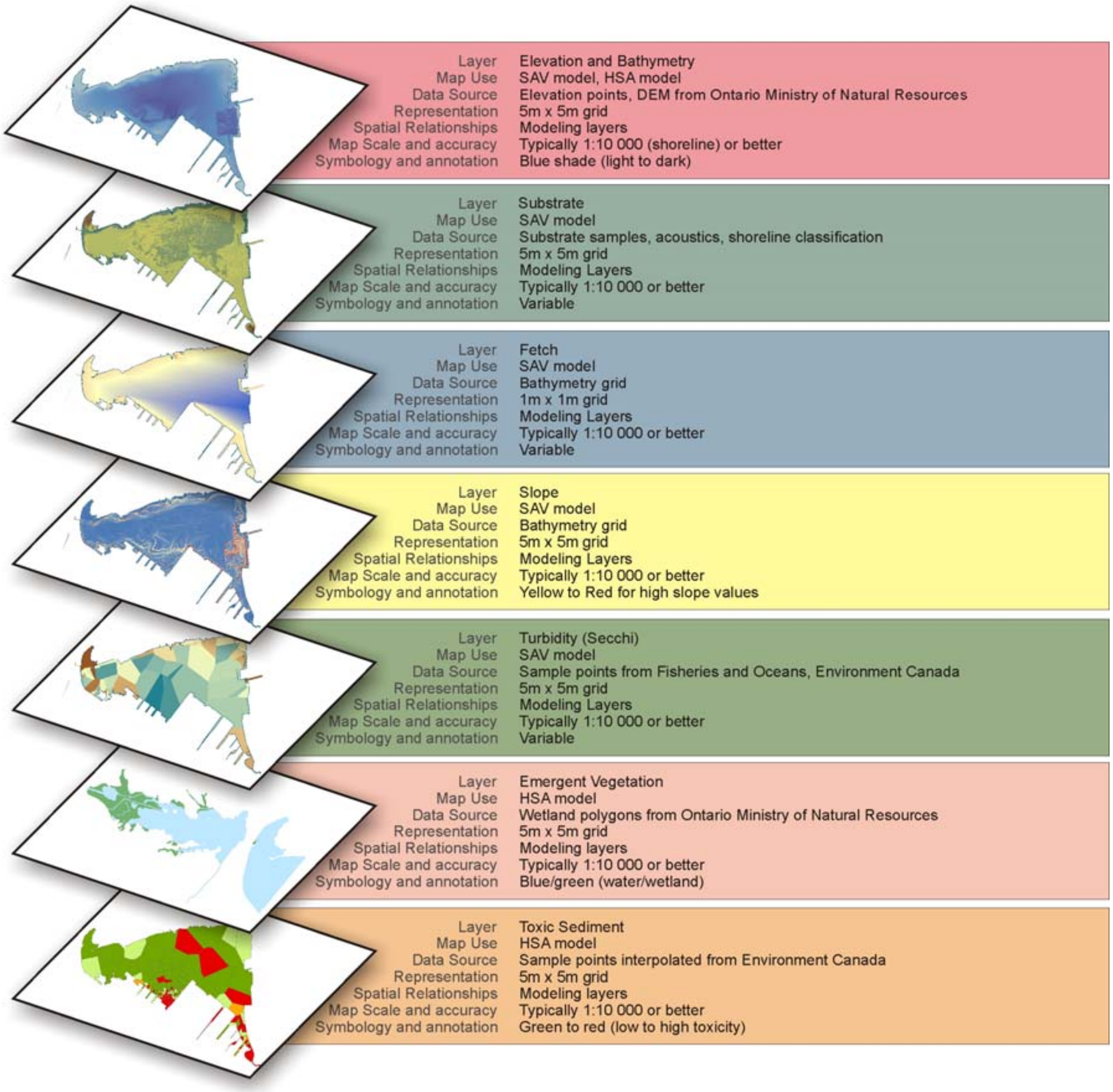

Figure 8. Simple modeling layers in the Hamilton Harbour geodatabase

3.2.3.1 <u>Elevation and Bathymetry:</u> "Historically, mean sea level (MSL) has been used as the zero of elevation."(Mahoney 2010). Conceptually, this fixed reference point is used to derive the elevation of a geographic location. This elevation reflects a vertical datum or reference point against which measurements are made. This vertical datum differs significantly from nautical chart or bathymetric data (or chart datum), which, for safety reasons, identifies the minimum depth of water that could occur at any point

(Canadian Hydrographic Service 2010). Therefore, synthesizing land and water elevations requires an adjustment so that all values reflect a single datum, whether land or chart-based, directed by the nature or goal of a project. For this project, all elevation values have been adjusted to chart datum (International Great Lakes Datum 1985, or IGLD85), maintaining a high level of accuracy in the bathymetric survey data, and facilitating the generation of a bathymetry layer using elevation values. Bathymetry data is one of the most important components to aquatic habitat modeling as it defines and describes the topology (shape) of the underwater space and its features that broadly define habitat for fishes.

Highly detailed bathymetric point data was assembled from single and multibeam surveys completed by the Canadian Hydrographic Service (CHS) in 2002 and 2005 (Leyzack, CHS, Burlington, pers. comm.). This data (n > 5 000 000), represented as points with associated depth values, were corrected to IGLD85, which is 74.2 m in Hamilton Harbour (Figure 9).

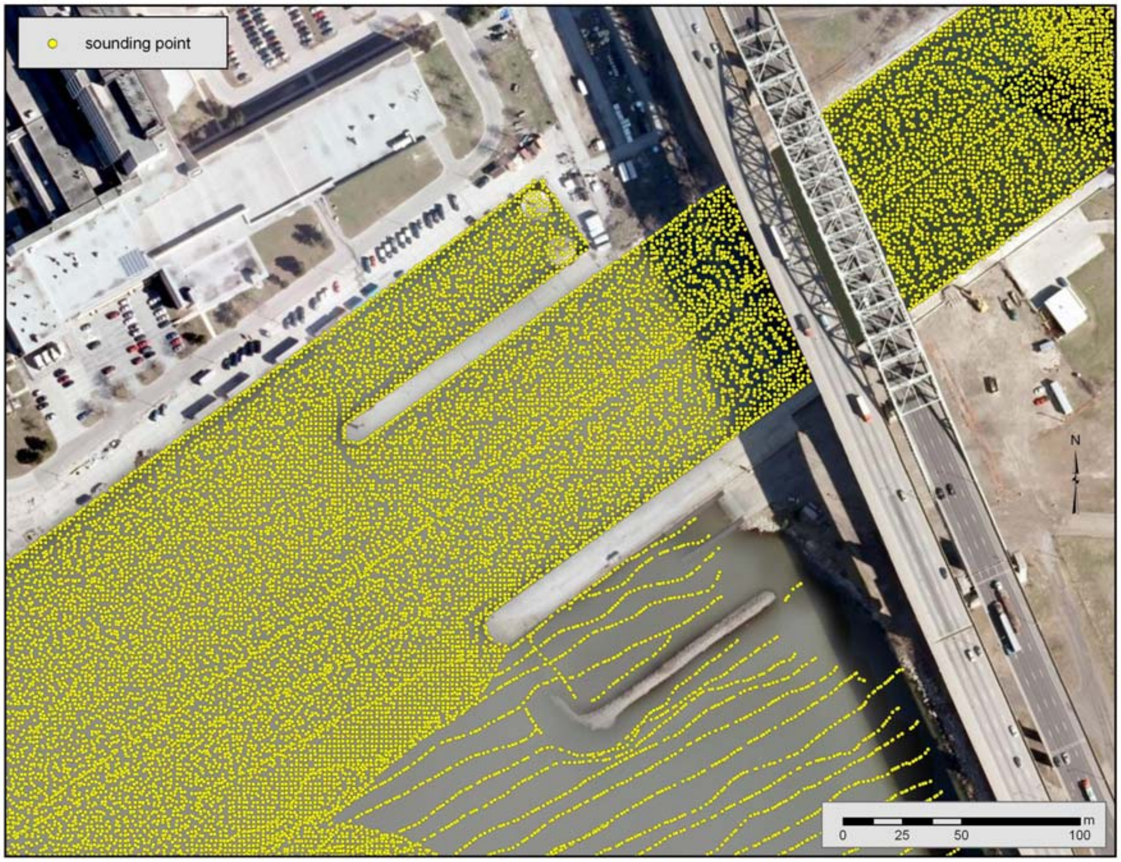

Figure 9. Example of Canadian Hydrographic Service (CHS) bathymetric survey Data in Hamilton Harbour from 2002 and 2005.

Computer-Aided Design data (CAD) from Windermere Basin was provided by the City of Hamilton, Public Works Department (Helka, Public Works Dept., Hamilton, pers. comm.). Soundings were extracted from CAD drawings and used in generating bathymetry points to align with CHS data and elevation values for the harbour (Figure 10).

Figure 10. Windermere Basin depth soundings from City of Hamilton Public Works Department, 2005.

The Ontario Ministry of Natural Resources (OMNR) provided a number of terrain datasets (derived from the Greater Toronto Area Orthophoto Project in 2002) for the Hamilton Harbour study area. The orthophoto project used soft-copy photogrammetric techniques to produce a highly accurate and precise elevation dataset. This was used to generate a digital elevation model (DEM) at a resolution of 5 m (+/- 0.5-1 m horizontal and vertical accuracy) along with other data products, like linear features such as shorelines, islands, breakwalls and waterbodies (Figure 11). Cartographically, these features are used in map production, to reflect a current picture of the harbour. They are also used to define extents of land and water features, and also to select data from the

DEM that could be used for interpolating elevations in the nearshore area where it was too shallow for bathymetric survey equipment.

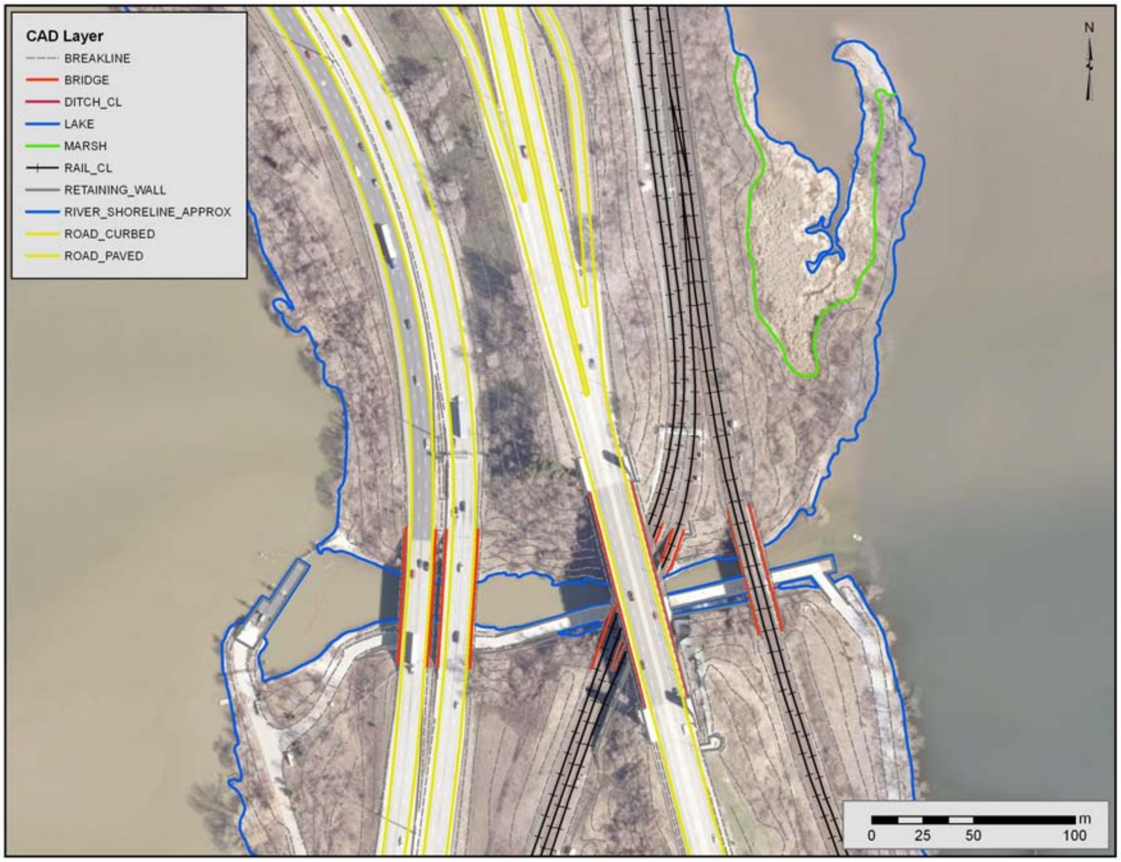

Figure 11. Example of Hamilton Harbour data provided by Ontario Ministry of Natural Resources (OMNR) showing features delineated using Orthoimagery in 2002.

Methods: Interpolation of elevations in the nearshore area was necessary to bridge the gap between adjacent land and seafloor elevations. Shoreline features were extracted from the CAD data (based on air photo interpretation done in 2002) to acquire an accurate and recent representation of the harbour. These shoreline features were used to identify the average extent of the water, or to be used as a "mask" for interpolation purposes. A 50 m buffer of the water features was created and used to extract elevation data from the detailed land DEM. Centroids of the grid cells were converted to points, and land elevation values were adjusted from the current height reference system (Canadian Geodetic Vertical Datum or CGVD28) to IGLD85 (i.e. subtracting 0.102 m from land elevations as a correction factor) (Herron, CHS, Burlington; pers. comm) using vertical benchmark data from the area (Sauvé, NRCAN, Ottawa, unpublished data (Figure 12).

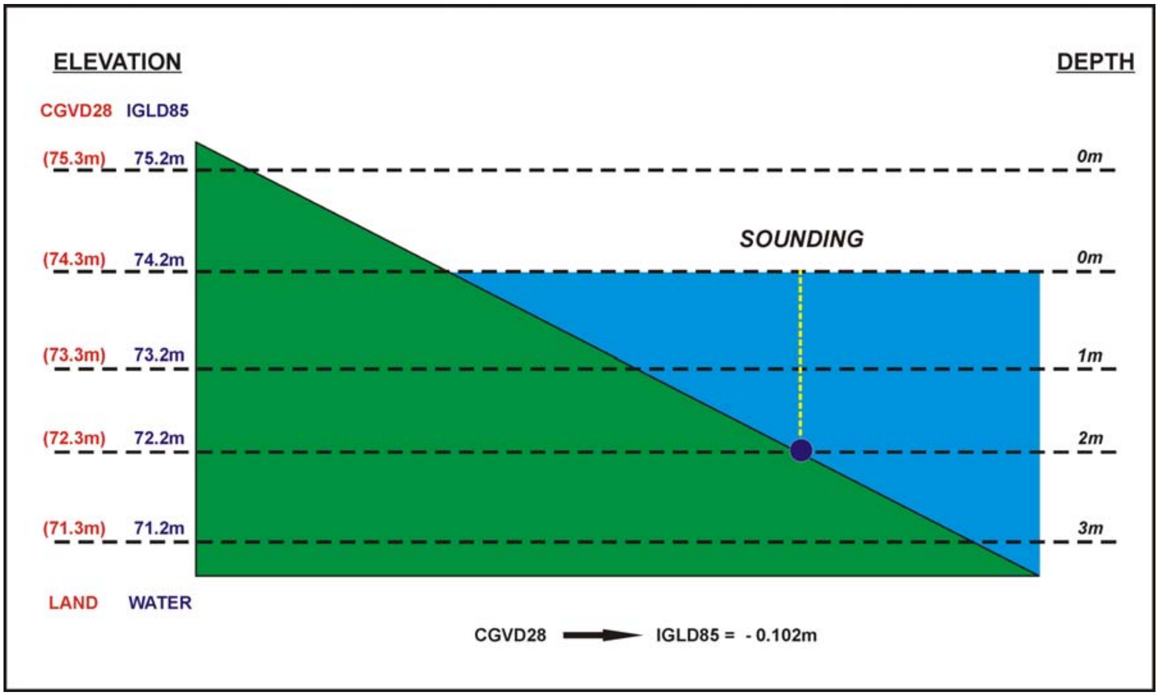

Figure 12. Vertical datum corrections for Hamilton Harbour land elevations.

Features that were not included in the bathymetric survey (man-made islands, docks, breakwalls, etc.) were added after the interpolation to ensure they were captured as part of the assessment.

Survey information from CHS was converted into an elevation value based on the IGLD85 datum of 74.2 m above sea level (5.0 m depth = 69.2 m elevation, or 74.2 m minus 5 m). These points were merged with the land elevation data into one layer.

Using ArcGIS™, a spline interpolation method was used to generate an elevation grid. This technique "minimizes the overall surface curvature, resulting in a smooth surface that passes exactly through the input points…and is best for generating gently varying surfaces such as elevation." (ESRI 2010d). The "tension" option was chosen in an effort to constrain the results based on the character of the data being modeled – in other words, to reflect the original sample data as closely as possible. Where land elevation values did not exist (particularly with small restoration islands), a value of 74.2 m (0 m depth) was assigned to ensure these features were not lost. These areas were spatially merged with the spline elevation grid. The final elevation grid facilitates the calculation of depth values using a standard calculation (Datum or water level elevation – interpolated elevation), and can be applied and/or modified to address different water level scenarios.

Final Elevation Layer: The final elevation layer (map) is a seamless coverage from land to water and can be used to represent both elevation and bathymetry (Figure 13). Since most of the work related to this project requires depth information, grid cell elevation values less than 74.2m (cut off for dry land) were extracted and a new bathymetry grid layer was created for modeling under a low water scenario (standardized).

Figure 13. Seamless Land/Water Digital Elevation Model (DEM) for the Hamilton Harbour area.

3.2.3.2 Substrate: Identifying and classifying substrate for Hamilton Harbour was a prerequisite for classifying fish habitat. A number of organizations have looked at classifying substrate type based on sample data collected at point locations (Rukavina and Versteeg 1995). For this analysis, data was assembled from various sources to compile and develop a comprehensive spatial layer of substrate compositions based on both qualitative assessments and quantitative grain size analysis.

Based on the assumption that the bottom composition of the harbour has not changed dramatically over the time of the surveys, point sample data has been obtained from a variety of sources and temporally spanned several decades. Core sample data collected by the National Water Research Institute (NWRI) from the 1980s and 1990s

(NWRI 1995) provided a solid foundation for the substrate layer. Recent point sample data was also used from DFO to fill gaps. Projects related to zebra mussels, electrofishing transect habitat surveys, and targeted habitat sampling (that included ponar, shoreline and acoustic surveys) provided quantitative and qualitative substrate data. Sample data has also been provided by EC (Milani 2010, unpublished data), CHS, and the Hamilton Harbour RAP (through detailed designs of restoration projects) (Hall, Hamilton Harbour RAP, Burlington, pers. comm.). Figure 14 represents all point samples used in creating a substrate layer for habitat assessments.

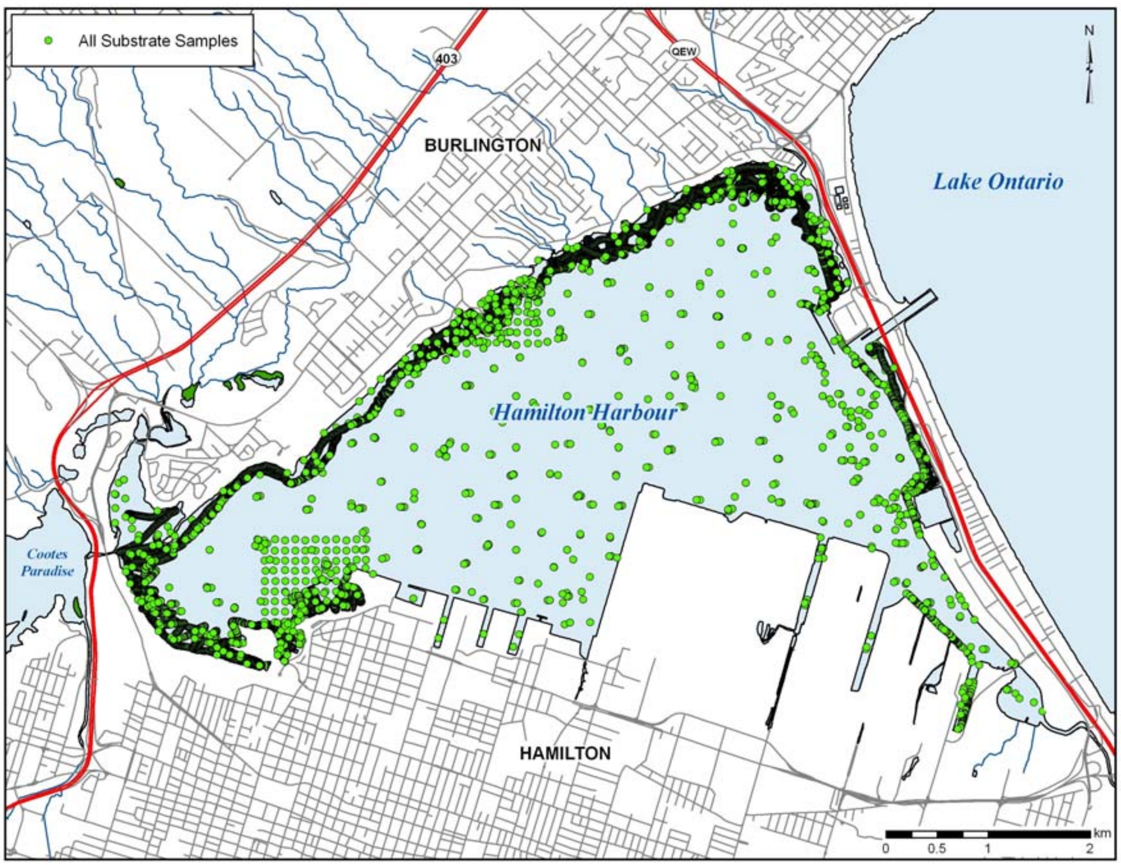

Figure 14. All substrate samples used in creating a substrate layer for habitat assessments in Hamilton Harbour.

In addition to point samples, a shoreline survey (with photos and samples) was conducted in 2006-2007 (Doka, in prep) was also used to attribute shoreline segments (shoreline features provided by the OMNR) with a general substrate composition. Polygon data contributing to the substrate layer was largely based on a visual assessment of detailed orthoimagery (Google 2007). The harbour high resolution photos provided data for features not captured in sample data, such as shallow shoals (Figure 15).

Figure 15. Google Earth™ imagery of shallow shoals that were digitized and used in creating polygon substrate data for Hamilton Harbour.

A final detailed source of substrate was multibeam backscatter data provided by CHS, used in conjunction with sample points in the "offshore" area of the harbour to classify substrate types into 4 discrete categories based on smoothness, size and composition.

Methods: Two areas (or zones) were used in the creation and interpretation of the final substrate layer – the nearshore zone and the offshore zone. Each zone represented a different spatial challenge for interpolation/classification methods based on available data (quantity and quality) and its interpretation (Figure 16).

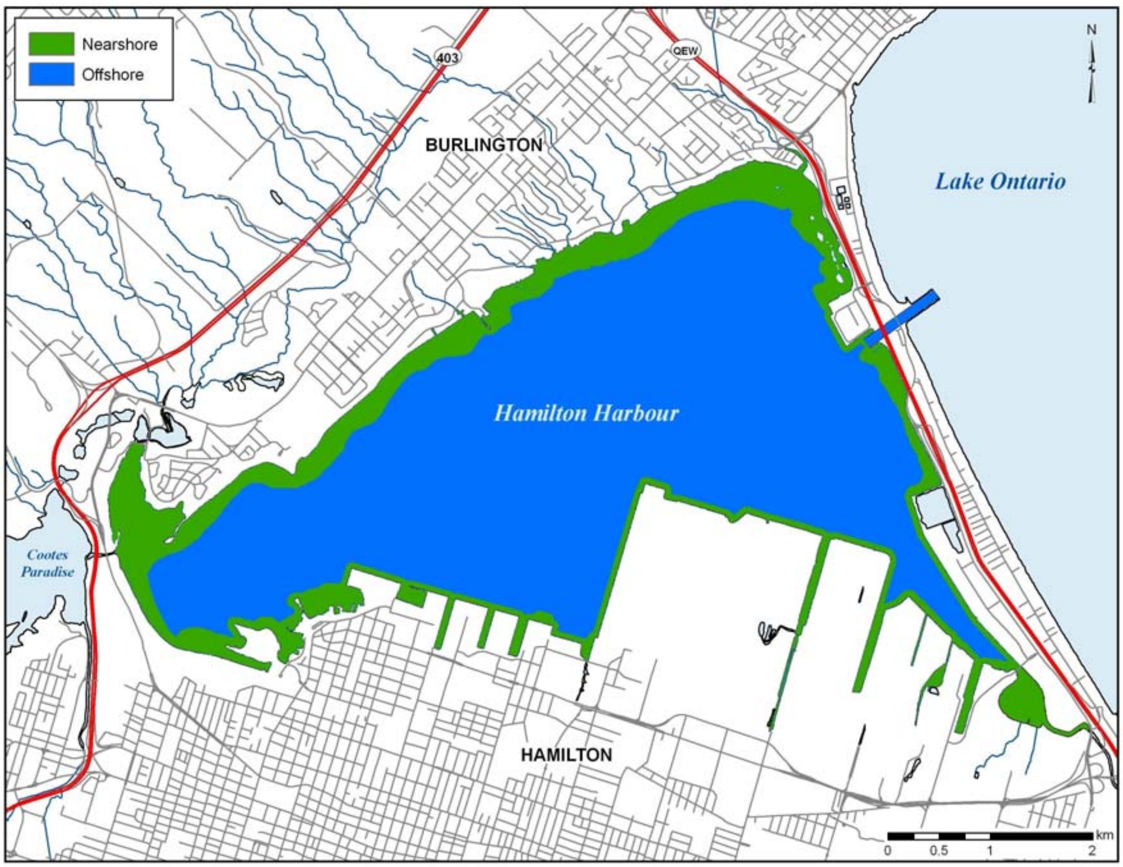

Figure 16. Nearshore/offshore substrate interpolation/classification zones in Hamilton Harbour.

Nearshore: Data compiled from a number of sources were assigned to specific classes (bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, hardpan, pelagic) described in Minns et al. (2006) and based on a modified Wentworth scale (Bain and

Stevenson 1999). Each substrate sample point was attributed with the percent composition of each class (e.g. 50% gravel, 50% sand) so that the total percent summed to 100%. Quantitative grain size samples used these classes listed above but could only capture grain size small enough to field sample (but percent composition are more reliable). Qualitative field measurements/visual assessments of substrate types classified as dominant, subdominant and trace were allocated percent values (post survey). Dominant and subdominant values were allocated percent compositions based on a ratio of to ⅔ to ⅓ (66% - 33%). If a visual sample had dominant, subdominant and trace values assigned, it was allocated percent compositions based on a 60:30:10 split (i.e. 60%-30%-10%).

It was necessary to use shoreline characteristics to fill gaps in the coastal area where substrate point data was sparse. A number of field methods were used to describe and assign the shoreline types and then to use those types to assign the substrate composition needed for modeling (e.g. bedrock, boulder, cobble, rubble, etc.) These methods included data collection with Global Positioning Units (GPS) to identify unique reaches, site photos for verification, and orthoimagery (Figure 17). See Doka et al. (in prep) for detail regarding the shoreline survey.

Figure 17. Example of shoreline survey segment with sample sheet, Bayfront Park, Hamilton Harbour.

Coordinates were taken with a GPS at each change in shoreline composition, and observations such as shoreline type, land-use and surficial nearshore geology were documented. Each segment represents a shoreline type different from its neighbour. Substrate samples were also taken at midpoints of segments to quantify and determine if shoreline substrate classifications could predict nearshore substrate type.

The following table outlines changes made to the original data based on how the original characteristic might emulate a type of substrate:

Table 3. Translation of shoreline survey type to percent substrate composition.

Original Description	% Functional Composition
Sand	100% Sand
Clay/Silt	50% Clay, 50% Silt
Gravel	100% Gravel
Cobble	100% Cobble
Gabian cribs	50% Cobble, 50% Boulder
Crib Dock	33% Rubble, 64% Cobble
Rubble	100% Rubble
Boulder	100% Boulder
Armour Stone	100% Boulder
Artificial Fill	100% Cobble
Bedrock	100% Bedrock
Steel Wall	100% Bedrock
Wooden Wall	100% Bedrock
Sand Barrels	100% Boulder
Zebra Mussels/Shells	100% Gravel

Shoals and man-made habitat features visible in the orthoimagery were digitized into polygons. Habitat structures used in restoration projects (materials ranging from cobble to armour stone blocks) were classified as either 100% cobble or armour stone, and subsequently converted to 5 m x 5 m grid cells.

A mask of the nearshore zone (areas <7 m) was created to facilitate the interpolation of sample points found within this zone, which is much different from the offshore substrates as it offers a more realistic representation and method for interpolation. Based on this notion, all point data were classified into two categories:

- Fine Substrate (gravel, sand, silt, clay)
- Coarse Substrate (bedrock, boulder, cobble, rubble)

The fine substrate point data were interpolated using a spline function to create a "smooth" surface within the nearshore zone. In an effort to closely reflect original sample data values, the "tension" option was chosen (for details see spline interpolation description in Elevation/Bathymetry methods section).

Coarse substrate points were buffered by 10 m and converted to grid cells, then superimposed on the soft sediment grid. This approach is based on the transitional nature of sand and silt areas transitioning to clay substrates in deeper waters throughout the harbour; much of the coarse substrate materials sampled (e.g. restoration structures, scattered boulders, shoals, etc.) are either rare in the offshore, or associated with mainly man-made shoreline features in the nearshore. A final grid representing all substrate (fine and coarse) in the nearshore was created; each cell's composition summing to 100% (Figure 18). Shoreline segments (line features) were converted into a 5 m grid cell raster to align with the original digital elevation model. This would eventually be used to supercede grid cell values extrapolated to the edge of the harbour.

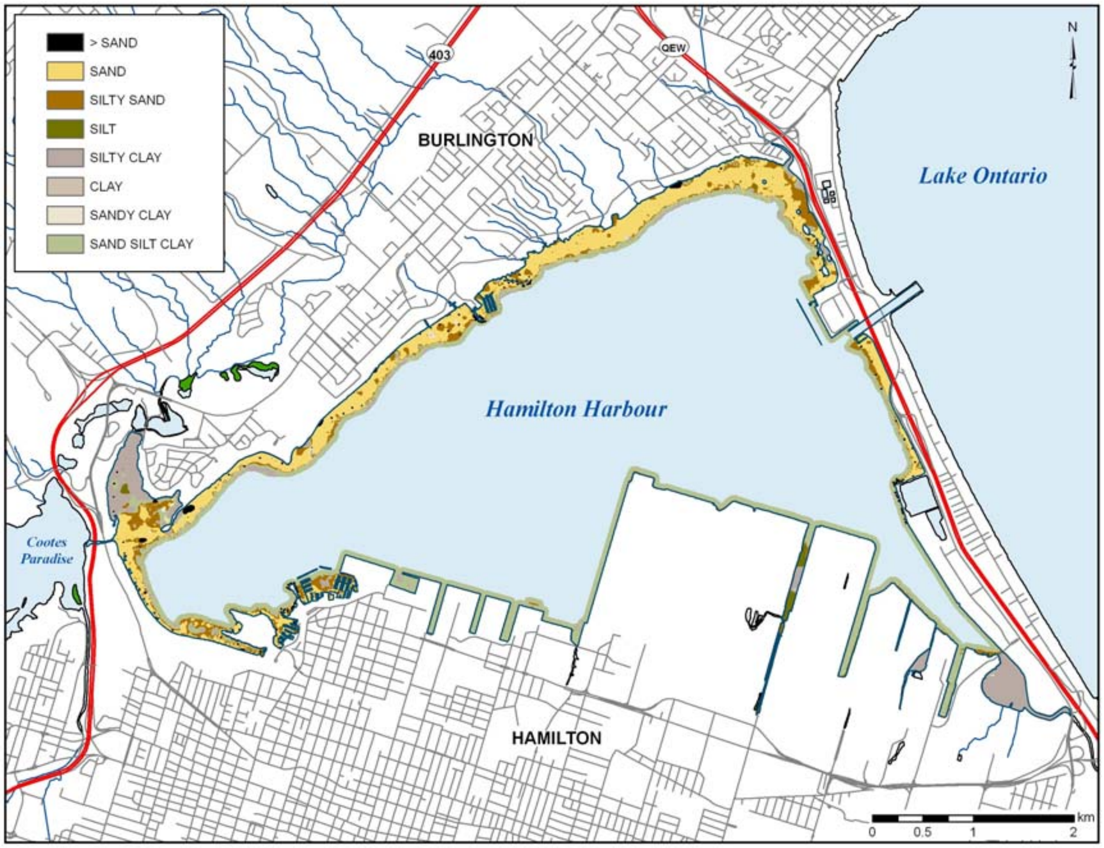

Figure 18. Classified substrate types based on the Shepard's Classification System (Poppe et al. 2003) to visualize the nearshore substrate composition layer for Hamilton Harbour.

Offshore: CHS collected multibeam bathymetric data for the harbour (Leyzack, CHS, Burlington, pers. comm.). This survey provided depth information (>5 m depth), and also contributed to the modeling of substrate data through expert interpreting and classifying backscatter data (Tekmap, unpublished data) collected from the multibeam Simrad EM3000 system.

The data stream from the Simrad system includes both depth and amplitude data. The amplitude data (or backscatter) data are a function of the angle at which the sonar beam reflects off the seafloor (grazing angle), the smoothness of seafloor, and the seafloor composition. After applying a series of backscatter correction functions, a simple reclassed map was created identifying four discrete classes (Table 5) representing backscatter acoustic ranges from the reflected multibeam: (Figure 19) (Tekmap, unpublished data).

Table 5. Discrete backscatter classes identified using acoustic ranges from the reflected multibeam.

Class	Backscatter start (dB)	Backscatter end (dB)
1	0.0	30.7
2	30.7	33.7
3	33.7	39.1
4	39.1	50.0

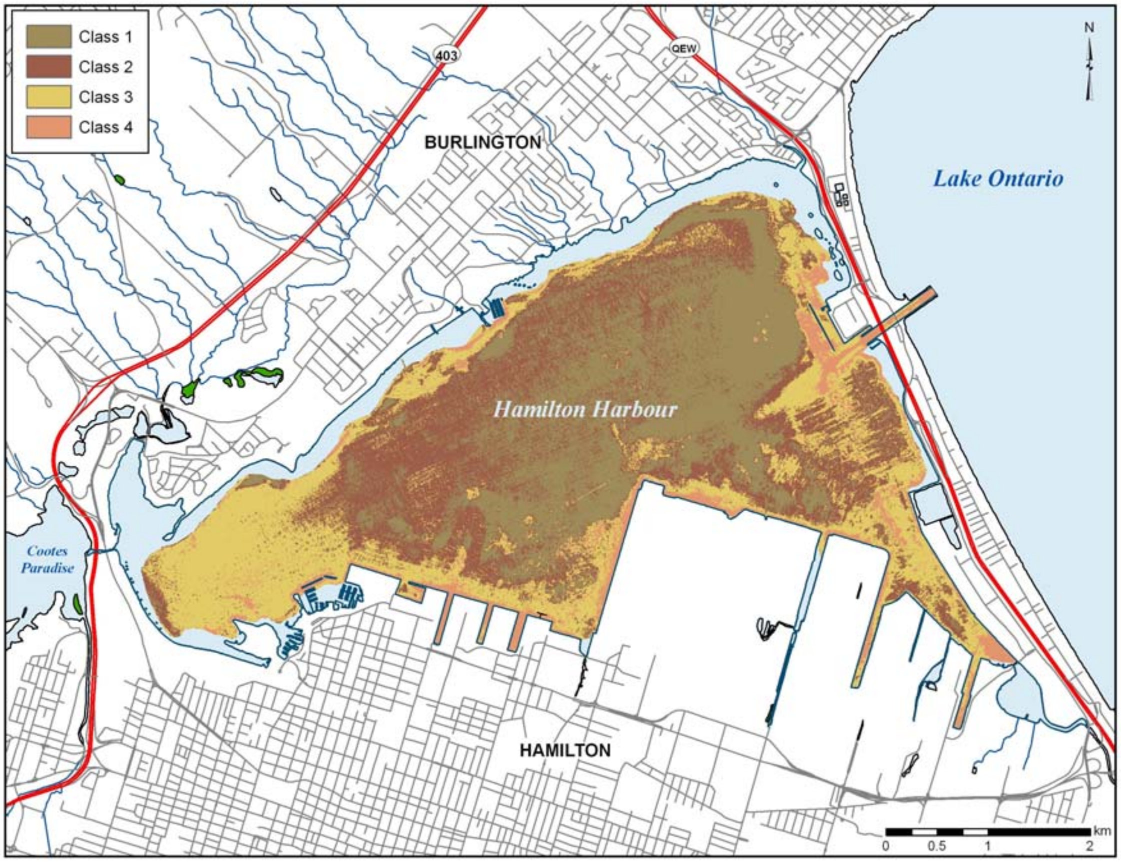

Figure 19. Mapping of backscatter interpreted classes in Hamilton Harbour using acoustic ranges from the reflected multibeam.

Classified backscatter information was averaged in the offshore zone. Offshore substrate samples were used to allocate a percent composition to each backscatter category. Sample points (processed samples) were spatially joined to grid cells at the same location. All values from the same backscatter class were averaged. The composition results are shown in Table 6.

Table 6. Backscatter class composition derived using samples from EC and NWRI.

Class	**% Composition**
1	0% gravel, 8% sand, 49% silt, 43% clay
2	0% gravel, 19% sand, 44% silt, 37% clay
3	1% gravel, 22% sand, 44% silt, 33% clay
4	0% gravel, 36% sand, 39% silt, 25% clay

As with the nearshore zone, points with larger substrata (> sand) were buffered and superimposed on the final grid layer to ensure this information was not lost due to the interpolation of predominantly fine substrate.

Final Substrate Layer: Interpolated and classified values within the nearshore zone, combined with the offshore classification, created a complete substrate layer with no data gaps (Figure 20). Represented as a 5 m cell size grid, this layer is used as a stand alone product, a component in predictive modeling of macrophytes (SAV), and as an input into fish habitat suitability supply or population models.

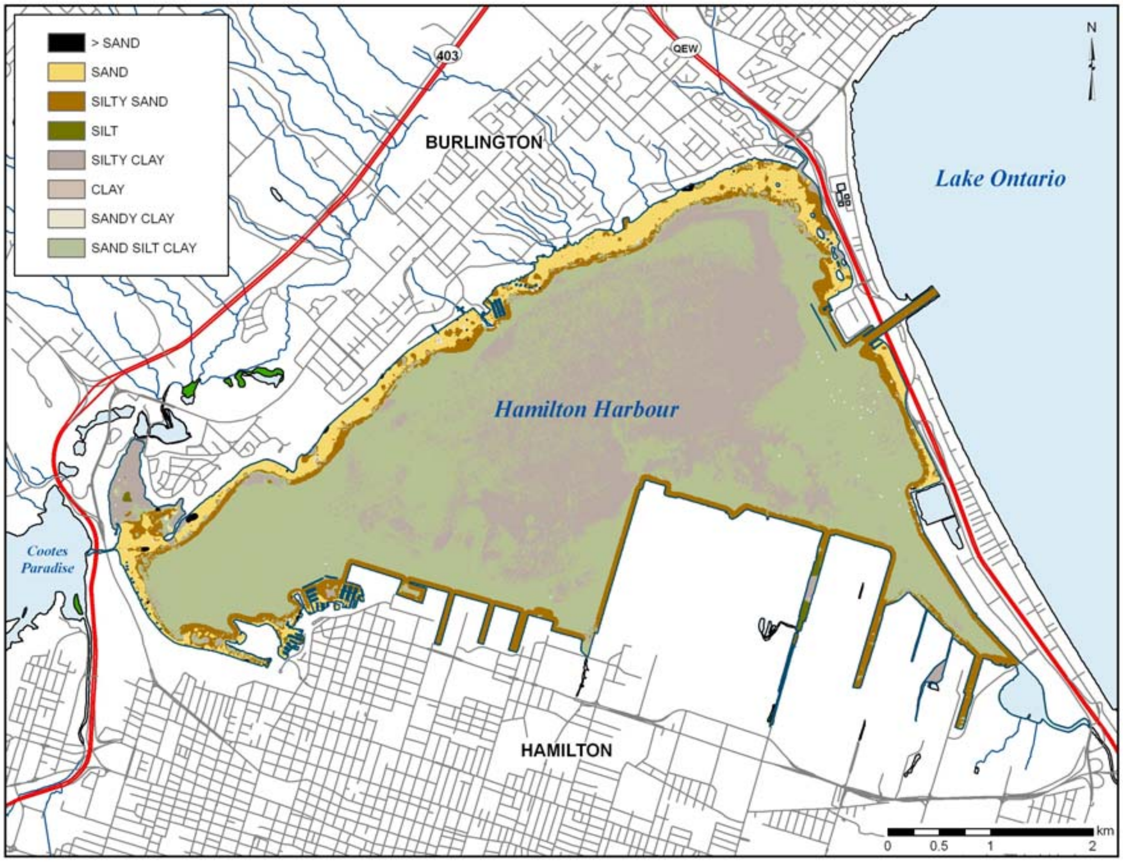

Figure 20. A complete substrate classification layer for Hamilton Harbour based on the Shepard's Classification System (Poppe et al. 2003).

3.2.3.3 <u>Fetch</u>**:** Fetch can be defined as "…the unobstructed distance that wind can travel over water in a constant direction" (USGS 2008). As a component to modeling submerged aquatic vegetation, fetch plays a key role in determining whether or not vegetation is able to colonize. Using a wind fetch and wave model created by the United States Geological Survey (USGS 2008), fetch was calculated for the harbour. This model generates fetch data at user-specified wind direction angles using a grid and specified shoreline. The extent of bathymetry grid for the harbour was used as the primary input for the fetch model. The model assumes that the input raster is properly projected in

Methods: The fetch model requires a number of inputs:

- *a land raster dataset* – values > 0 indicate land, <= 0 or NODATA indicate water
- *a wind direction list* – text file containing values of wind directions (angles from which fetch data is needed)
- *a calculation method* – three different calculation methods are available, 1) SPM, 2) SPM restricted, and 3) Single.

A land raster dataset was created from the DEM. Land grid values were re-classed to 99 (i.e. Elevation > 74.2 m) and water grid values were set to 0. In 2007, there was a dominant westerly wind (or 270°) in Hamilton Harbour, and a text file was created to reflect these average conditions. The "SPM" method was chosen as it uses a recommended procedure from the Shore Protection Manual (U.S. Army Corps of Engineers 1984), spreading 9 radials around the wind direction in 3-degree increments and averaging the values.

Final Fetch Layer: The result of the "SPM" model is a grid of values which identifies the distance to shore based on the directions identified in the text file. With a dominant westerly wind in 2007, the year that the submergent vegetation was sampled, it is apparent that higher fetch values are found in the east end of the harbour. This grid was used in the generation of a submergent vegetation model for the harbour (Leisti, Bouvier and Doka, pers. comm.) (Figure 21) as wind driven forces determine vegetation presence (Baird 1996). However, fetch could also be useful for hydrodynamic and other biotic models.

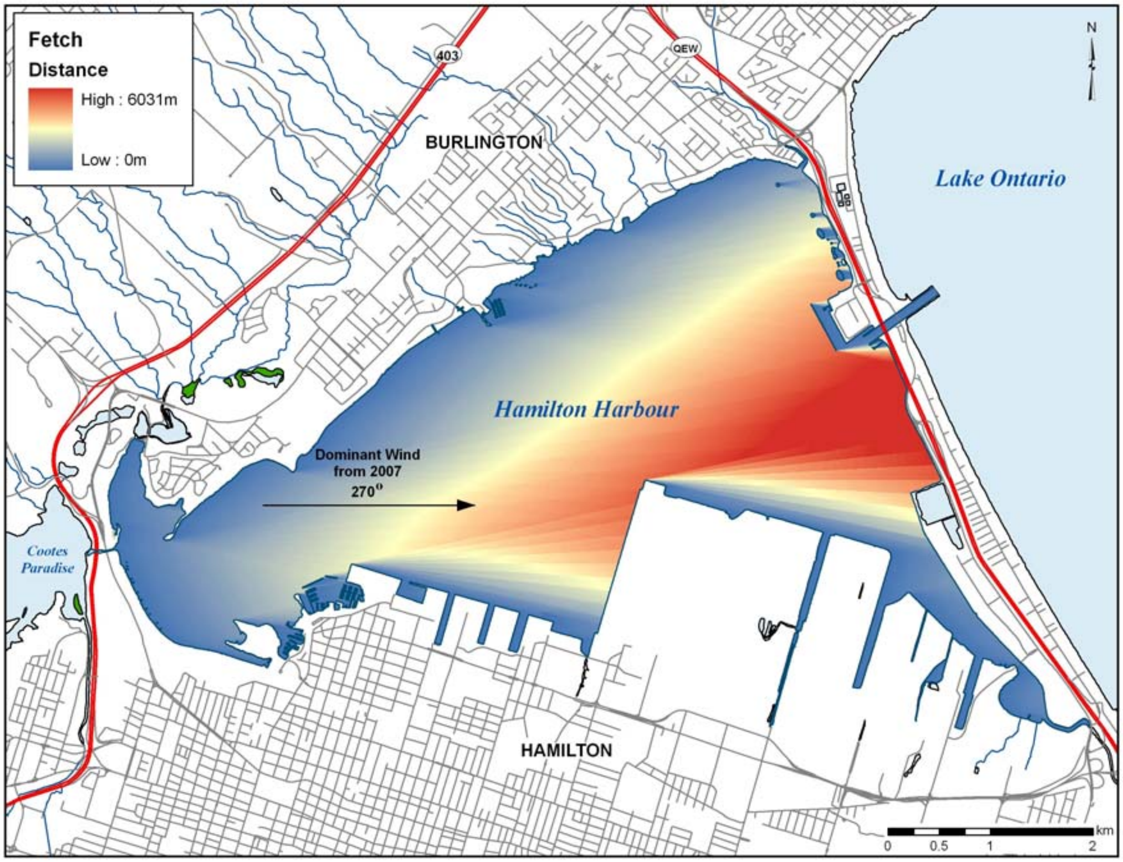

Figure 21. Average fetch for Hamilton Harbour from prevailing wind (270°) in 2007 (year macrophyte survey was completed).

3.2.3.4 Slope: In previous studies, the relationship between slope and macrophyte growth has been examined. According to Duarte and Kalff (1986), "there is a great influence of the slope of the littoral on the biomass of submerged macrophyte communities." This conclusion based largely upon the physical stability of the sediment, and impacts of erosion. The bathymetry grid was used to generate slope values for the harbour based on elevation changes.

Methods: Slope can be calculated in degrees or as a percentage, and the lower the calculated slope value, the flatter the surface. Percent slope was obtained using ArcGIS ™ Spatial Analyst, derived by calculating the maximum rate of change between each grid cell and its neighbours (rise/run * 100). For example, the steepest downhill descent for the cell (i.e. the maximum change in elevation over the distance between the cell and its eight neighbors) (ESRI 2010e).

Final Slope Layer: The final slope layer was a 5 m x 5 m grid resolution where each cell represented a percent change in slope value (Figure 22). On average, the steepest slopes were found in the 2-5m depth range, along breakwalls, and on the southeastern shore where excavation/dredging deposits had occurred.

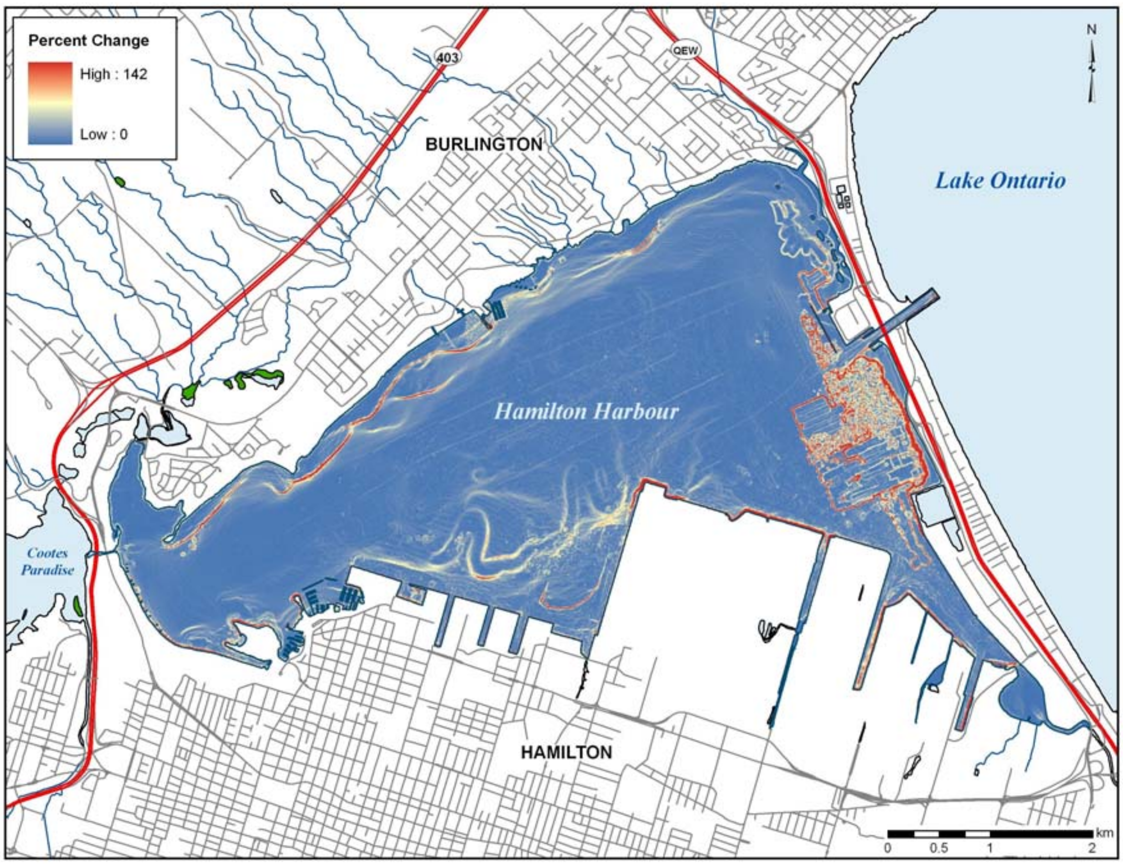

Figure 22. Slope (represented as percent change) for Hamilton Harbour derived using ArcGIS™ Spatial Analyst showing high to low values.

3.2.3.5 <u>Turbidity (Water Clarity/Secchi Depth)</u>: Turbidity refers to how clear the water column is. High concentrations of particulate matter can modify light penetration….reduced significantly, macrophyte growth may be decreased."(NRRI 2010). Particularly within Hamilton Harbour, water clarity impacts aquatic vegetation growth by restricting light from penetrating into the water column. Apart from sediment re-suspension from within the harbour, there are turbid inputs such as the outflows of Grindstone Creek in the west (Figure 23) and Indian Creek in the east.

Figure 23. Example of turbid input from Grindstone Creek in Hamilton Harbour, delineated using Google Earth™ imagery and used to model final turbidity layer.

Point data from DFO (Doka et al. unpublished data) and EC (Hiriart-Baer et al., unpublished data) was compiled to create a layer for spatial water clarity. This layer would be used as an input to the SAV model. Secchi depth values were collected at a number of locations across the harbour (although spatial coverage was poor), often seasonally and occurring at different depths (maximum depth of 3 m).

Methods: Point data for Secchi depths were used to interpolate a turbidity layer for Hamilton Harbour. A Spline method (with a smoothing factor of 0) was used in an effort to spatially represent Secchi depths in the harbour as a whole. Grindstone Creek and Indian Creek are known to have high turbidity values, resulting in "plumes" was extend out into the harbour. Based on orthoimagery, the average extent of these plumes were captured in a GIS and merged with the Secchi grid. Values in these areas are known to have limited macrophyte growth, and in an effort to model macrophyte coverage, lower Secchi values have been attributed to these plume areas.

Final Secchi Depth Layer: The Secchi layer represents a preliminary assessment of collected samples and interpreted turbid input in the harbour (Figure 24). Further analysis is needed to ensure that the interpolated layer accurately represents the characteristics of the phenomena being represented. This includes an investigation into turbid inputs such as Grindstone Creek, Indian Creek and Cootes Paradise, and their temporal or permanent influences on water clarity that may restrict macrophyte growth in the harbour.

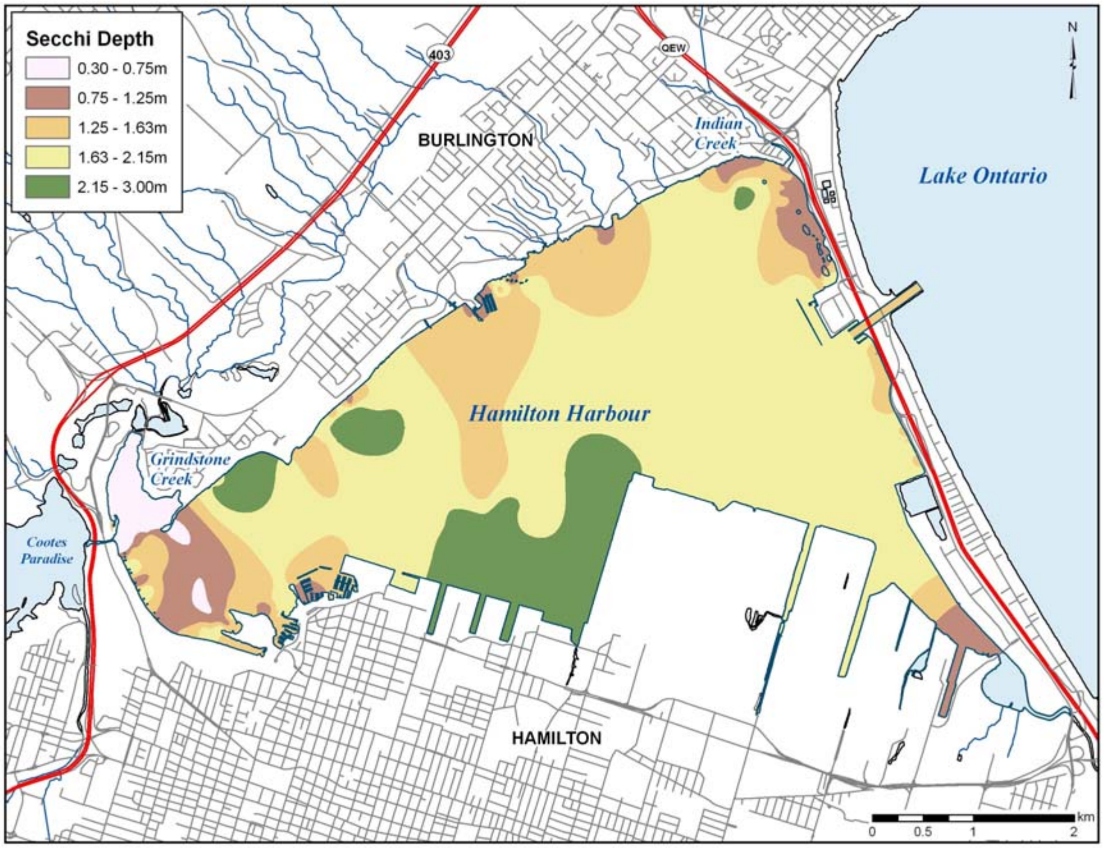

Figure 24. Final Secchi depth layer for Hamilton Harbour generated using a Spline method to model submergent vegetation.

3.2.3.6 Toxic Sediment: A sediment toxicity layer was created to define areas that might be toxic to aquatic vegetation and biota, including fishes or their habitat. This layer serves as a “mask” to spatially identify highly toxic areas that should be remediated or avoided for restoration initiatives.

Sample point data provided by EC (Milani and Grapentine 2006b) has been classified into distinct levels of toxicity based on lab assays: Non-toxic, potentially toxic, toxic, and severely toxic (Milani and Grapentine 2006a). In total, 177 sediment samples collected between 2000 and 2006 were provided. The spatial distribution of samples are directly correlated to reference sites throughout the harbour, with significant clustering of samples in known, highly-toxic areas especially the Randle Reef area to the south and the Windermere Arm to the east (Figure 25).

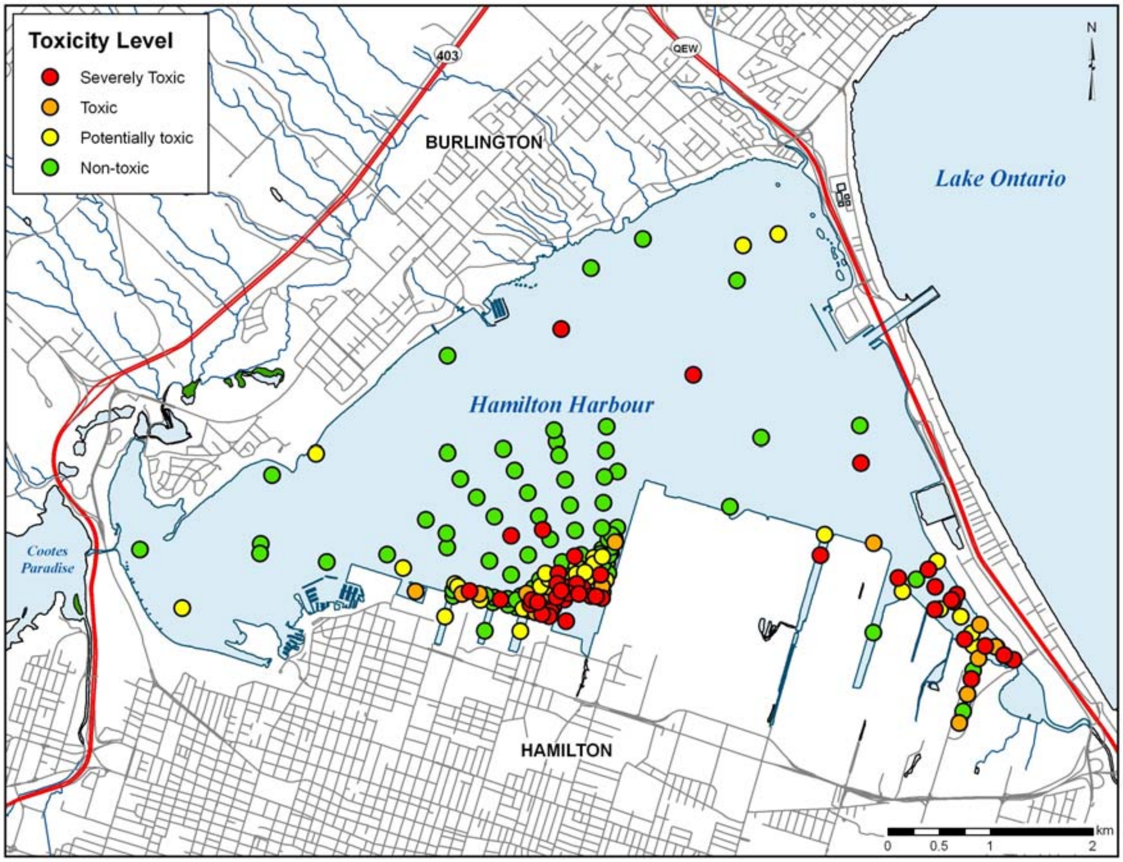

Figure 25. Hamilton Harbour sediment toxicity classes from laboratory toxicity assays conducted from part sampled sediments (Milani and Grapentine 2006b).

Methods: Sample points were interpolated using a Spline method (with a smoothing factor of 0) in an effort to spatially represent toxicity in the harbour as a whole. This is currently a draft output. Additional statistics will be conducted to ensure that areas are not under/over represented, and that the interpolated results represent an accurate picture of toxic sediment in the harbour.

Final Toxicity Layer: The final toxicity layer represents a generalized map of toxicity in Hamilton Harbour. The interpolation method makes obvious assumptions about distributions of contaminants and toxic zones (evident in some of the larger areas represented by one point). Likely, further research is needed to investigate spatial patterns, including potentially modeling sediment transport, as well as current and wave impacts on nearshore sediments. A draft interpolated result can be seen in Figure 26 highlighting some of the issues raised and zones potentially needing further investigation (Marvin, pers. comm.).

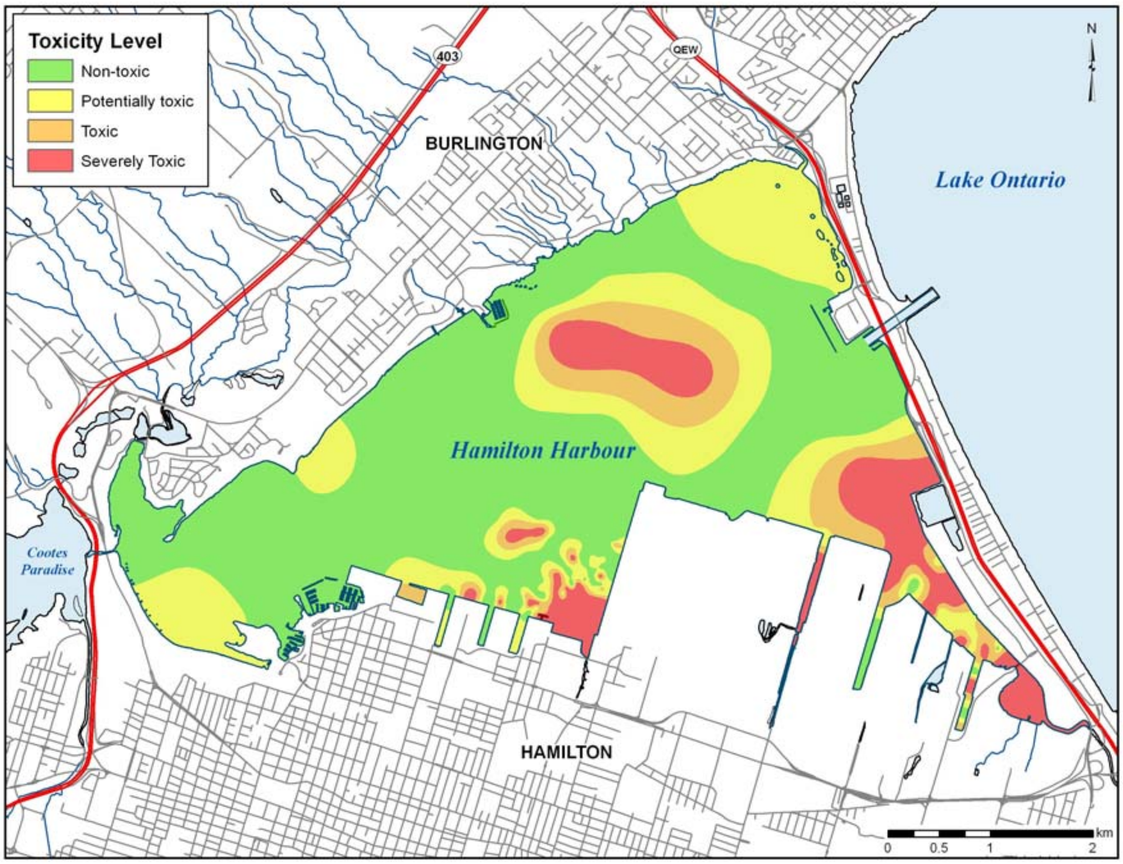

Figure 26. Draft sediment toxicity levels in Hamilton Harbour as determined by interpolating classified point sample sediments using a Spline method (Milani and Grapentine 2006a).

3.2.3.7 Aquatic Vegetation: Generation of a final aquatic vegetation layer requires two vegetation input layers, including (1) emergent vegetation, and (2) submergent vegetation. Each will be discussed in detail below.

1. Emergent Vegetation

"Marshes are typically characterized by emergent vegetation and relatively high oxygen levels in the rooting zone. The vegetation often shows distinct zonation with changes in water depth and exposure to wave action." (Newmaster et al.1997). Emergent plants provide valuable cover and habitat for aquatic species, including nursery habitat for young fish and adults, and spawning habitat for some species.

Emergent vegetation for Hamilton Harbour was provided by the OMNR.

Methods: Emergent vegetation or wetland areas that were visible or classified from the 2002 orthoimagery were converted into a 5 m resolution wetland grid for the Hamilton Region. When converting vegetation layers into cover, an assumption was made that emergent wetlands represent high density cover (100% cover). Another assumption would be that emergent vegetation extents changed or new wetlands have not appeared since that time and this generally represents current conditions.

Final Emergent Aquatic Vegetation Layer: The final layer represents emergent vegetation in Hamilton Harbour, which is represented as a 5 m x 5 m grid from 2002 (Figure 27).

Figure 27. Example of an emergent aquatic vegetation polygon from Hamilton Harbour.

2. Submergent Vegetation

Submergent aquatic vegetation is used by all trophic levels of the ecosystem, providing life-cycle necessities including nutrients and shelter. Mapping SAV requires a significant amount of field time to effectively capture the spatial distribution within a given area because remote aerial sensing may not work and ground truthing is necessary. With a surface area of approximately 200 km^2, an exhaustive spatial survey of Hamilton Harbour was not feasible. Therefore, the development of an SAV model was necessary to predict SAV presence and percent cover in Hamilton Harbour from empirical relationships and various datasets including field transect data (Leisti, Bouvier and Doka, pers. comm.).

Primary inputs to the percent cover model included elevations, slope, and effective fetch. Depth (derived from the elevation layer) and Secchi were also used to predict SAV presence based on light penetration to support plant growth in different turbidity zones (Figure 28).

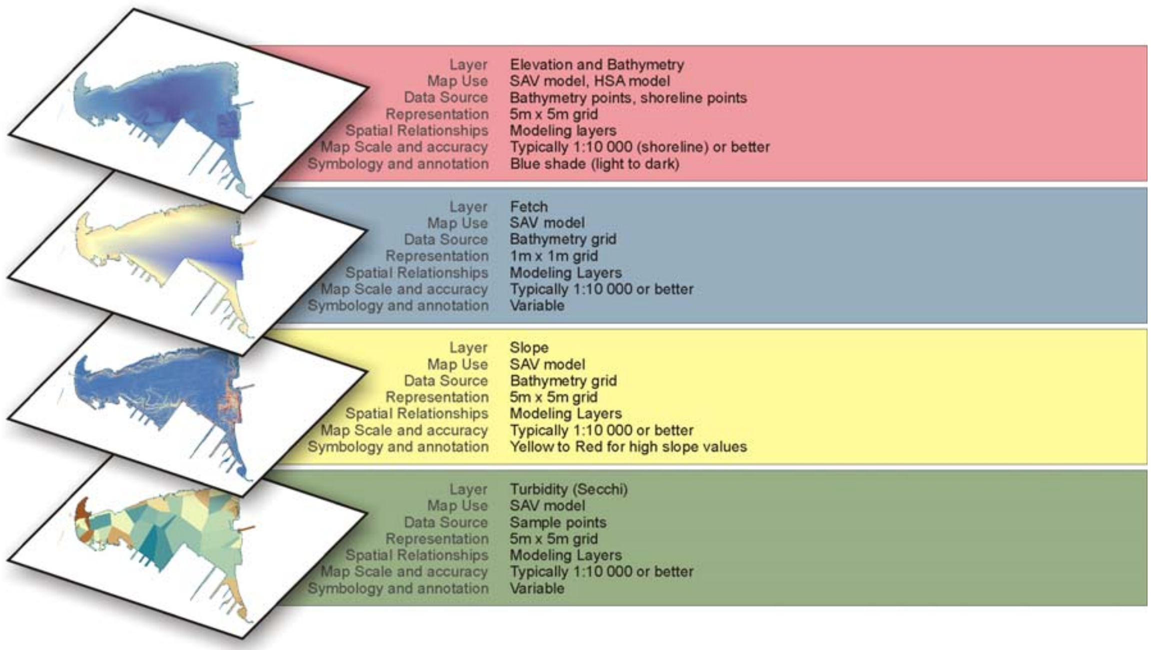

Figure 28. Submergent aquatic vegetation model layers.

Methods: Using a multiple linear regression equation for percent cover, input grids were combined into a percent cover value and then classified. In the establishment or growth of vegetation, certain variables are weighted higher in the predictive regression model than others. The following formula was applied:

Percent Cover SAV = 86.3783 + (-0.7201 * [ps]) + (-10.4607 * [d]) + (-0.0099 * [ef]) + ([d] - 2.3082) * ([d] -2.3082) * -3.3981 + ([d] - 2.3082) * ([ef] – 1299.6220) * 0.0026

ps = percent slope
d = depth
ef = effective fetch at @270° (Leisti, Bouvier and Doka. pers. comm.)

The final classification assigns a percent value to each cell based on every value or variable input into the model. Grid cells with a depth > 5.75 m (maximum depth of colonization), as well as those that have a Secchi value of < 0.6 m (insufficient light penetration to support plant growth), were removed from the analysis (set to 0% cover).

Submergent Aquatic Vegetation Layer: The preliminary SAV layer represents a synthesis of habitat features or characteristics that are required or limit macrophyte growth (Figure 29). This layer will likely be further modified for Hamilton Harbour specific conditions that could further limit this predicted coverage of SAV, especially by toxic sediments in slips and the Randle Reef area where vegetation growth has yet to be verified.

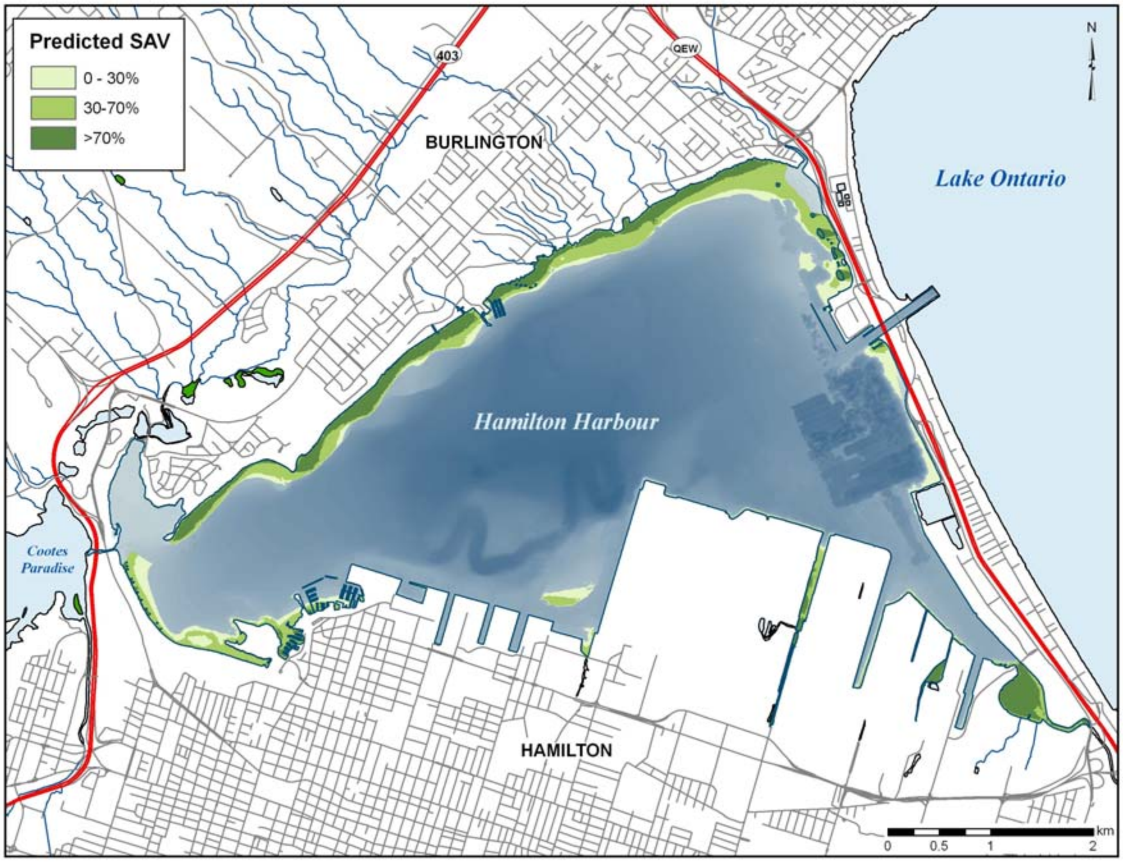

Figure 29. Predicted SAV (% cover) for Hamilton Harbour based on current conditions.

Aquatic Vegetation: Aquatic plants, both submergent and emergent, provide a foundation and support for local food webs and are indicators of healthy systems (Jeppesen et al1998). In Hamilton Harbour, a GIS layer was created to capture the spatial extent of all aquatic vegetation, both emergent and submergent.

Methods: The HSA model requires vegetation to be classified into categories of emergent, submergent, or no cover. Combining results from the submergent aquatic vegetation layer (predicted % cover) and the wetlands layer (100% cover) provided a means of generating the layer needed. While there are limited emergent wetlands within Hamilton Harbour, these two layers could potentially overlap. In these situations, a hierarchical method was used and tested to assign a value. If emergent vegetation exists, and there is no predicted submergent cover, then the emergent value is used (e.g. 100% emergent). If there is overlap of emergent and submergent data, the predicted SAV value takes precedence and the remainder is classified as percent emergent (e.g. 50% SAV, 50% emergent). If the predicted cover does not equal to 100% and there is no emergent, the remainder is % no cover (e.g. 60% SAV, 40% no cover). Where there is no vegetated cover, it is classified as 100% no cover.

Final Aquatic Vegetation: The final aquatic vegetation layer is represented as a 5 m grid, containing submergent, emergent and no cover % values (Figure 30).

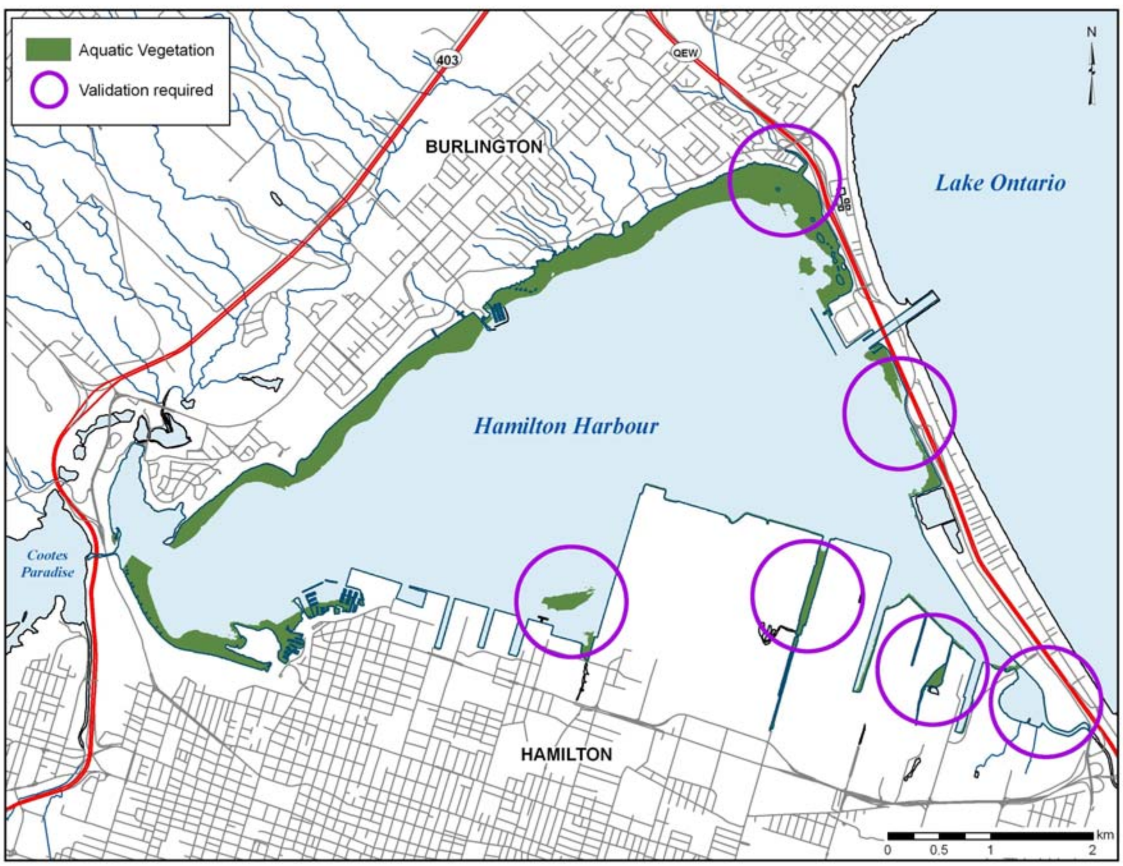

Figure 30. Draft aquatic vegetation layer for Hamilton Harbour, highlighting areas where validation is required and where toxic sediment and water quality layers may overrule.

4.0 RESULTS

4.1 HAMILTON HARBOUR GEODATABASE STAGE 3: TESTING

The testing stage provides an opportunity to query, extract, and report on the data, and evaluate if all project requirements have been met. For this case study, the testing stage reflects various steps used in generating input and receiving output from the habitat models, as well as any input layers used directly in the models.

4.1.1 Fish Habitat Suitability Analysis

Fish habitat suitability analysis for Hamilton Harbour uses a number of habitat layers. At minimum, these layers can be used:

- Vegetation: Submergent vegetation and emergent vegetation are combined to represent an overall percent cover (percent no cover, percent emergents, percent submergents).
- Depth: Categorized into classes including 0-1 m, 1-2 m, 2-5 m, 5-10 m, >10 m.
- Substrate: Percent composition categorized into bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, hardpan, pelagic (Figure 31).

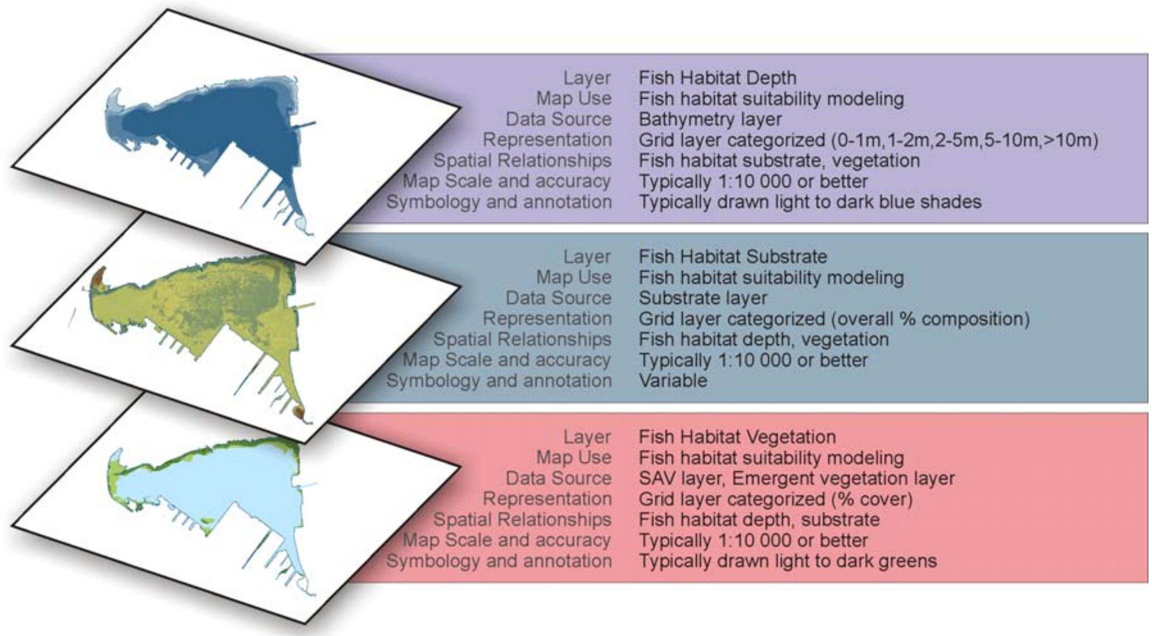

Figure 31. Fish Habitat Suitability model requirements.

Methods: A spatial overlay of three habitat layers produced a new layer that combined all habitat characteristics and attributes together. A layer with unique combinations of habitat characteristics was generated, which lumped areas with identical habitats while ensuring a unique identifier could be used to remap the output results back and summarized into a table that was used as input to the HSA. Specifically, requirements of the model include:

- A unique ID (assigned based on unique combinations of all variables)
- Total area (of each unique combination)
- Area type (changed or unchanged) for pre- and post-scenario assessment
- Depth (classified into categories: 0-1 m, 1-2 m, 2-5 m, 5-10 m, 10 m+)
- Substrate (% of bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, hardpan or pelagic)
- Vegetation (classified into categories: % no cover, % emergent, % submergent).

For a detailed look at the input table, see the example in Appendix 1.

Fish Habitat Suitability Layer - Example: Once these variables were processed by the model (e.g. Minns et al. 1997) the output from the model was remapped and classified by habitat suitability for different life stages (adult/spawning/young of the year), and thermal preference (cold, cool, warm). Combining all species together for a composite suitability index reflects the fish community's habitat needs as a whole, ranked from 0 (low suitability) to 1 (high suitability). For a detailed description into habitat suitability matrix (HSM) input requirements and output results, see the report from Minns et al. (2006). Initial results from the HSA model can be seen below, and is used to illustrate the type of model output. When testing the output, it is possible to identify where adjustments are required (e.g. Randle Reef) in either the data or the modeling (Figure 32).

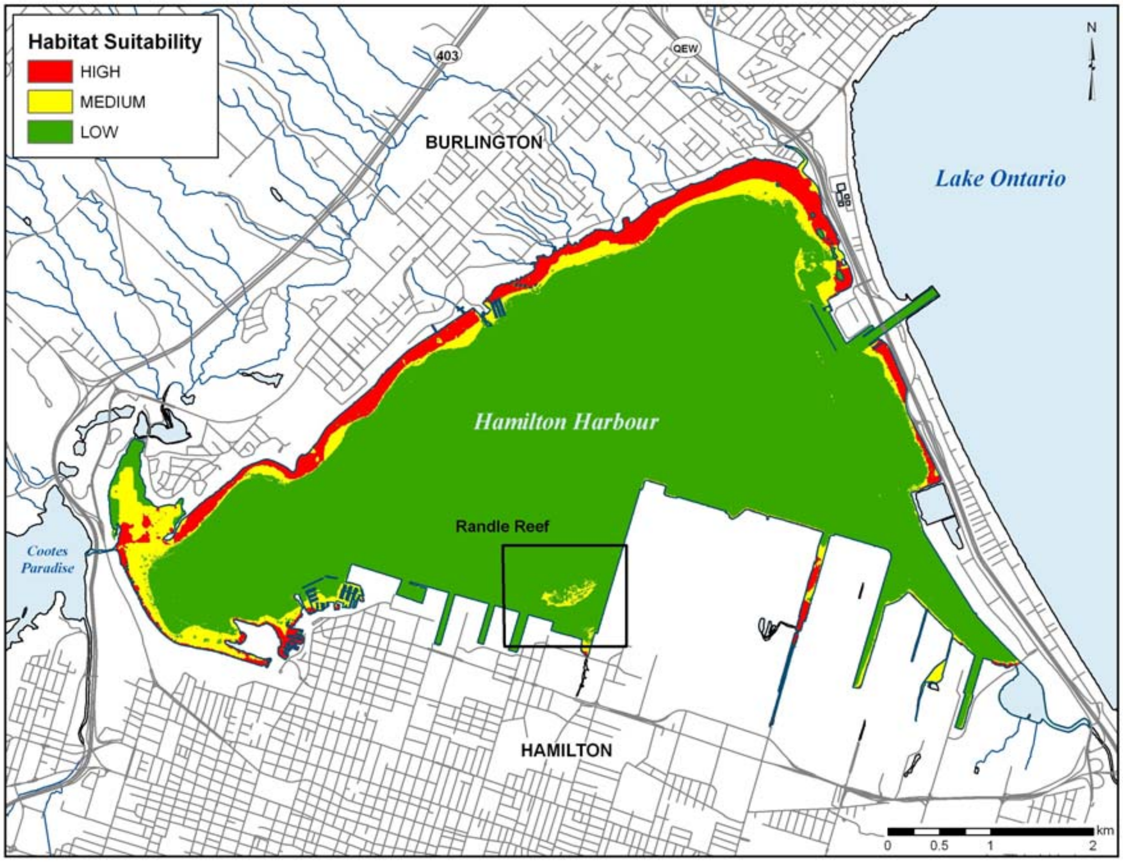

Figure 32. Draft output of high, medium and low suitability ranges for Hamilton Harbour fish communities using the HSA model.

4.2 HAMILTON HARBOUR GEODATABASE STAGE 4: IMPLEMENTATION

The implementation stage is the desired goal or "end-result" of the geodatabase. The framework used in generating the output for the HSA is one of the final products of the geodatabase, although the results are still preliminary. Implementing the fish habitat data model (structure, format and concepts) will facilitate work in other areas, especially AOCs, where an area-based or an ecosystem approach is required.

4.2.1 The Fish Habitat Data Model

The Fish Habitat Data Model integrates information from a variety of sources, in a variety of ways. Consolidated "views" of habitat information from different agencies have contributed to the generation of thematic spatial data (represented as points, lines and polygons). These core spatial datasets provide the foundation to the development of other complex or modeled fish habitat layers, and provides components to other modeling efforts, such as HSA models.

For modeling fish habitat, the value and importance of incorporating raster data becomes apparent. Orthoimagery, one form of raster data, can be used as a mapping reference, but also as an indicator of change in a study area over time (with a series of images). Using a raster to map data can also be an effective method to present information (such as elevation, temperature, etc.) as a continuous surface. Much of the modeled data is continuous, and opportunities exist to include other valuable information, such as temperature. Categorizing raster data into discrete classes provides a means for grouping and mapping thematic data. This method was used in a number of grid layers including the toxicity layer (grouped by level of toxicity) and the final habitat suitability layer.

Development of each spatial layer or grid can be completed separately, however, spatially it is important to ensure that these grid cells align spatially. In doing so, one can visually recognize spatial patterns, further analyse and assess this information, and demonstrate to others how the spatial influence of factors (e.g. aquatic vegetation) can contribute to the overall health of ecosystems. Figure 33 represents a "simplified framework" of the Hamilton Harbour geodatabase.

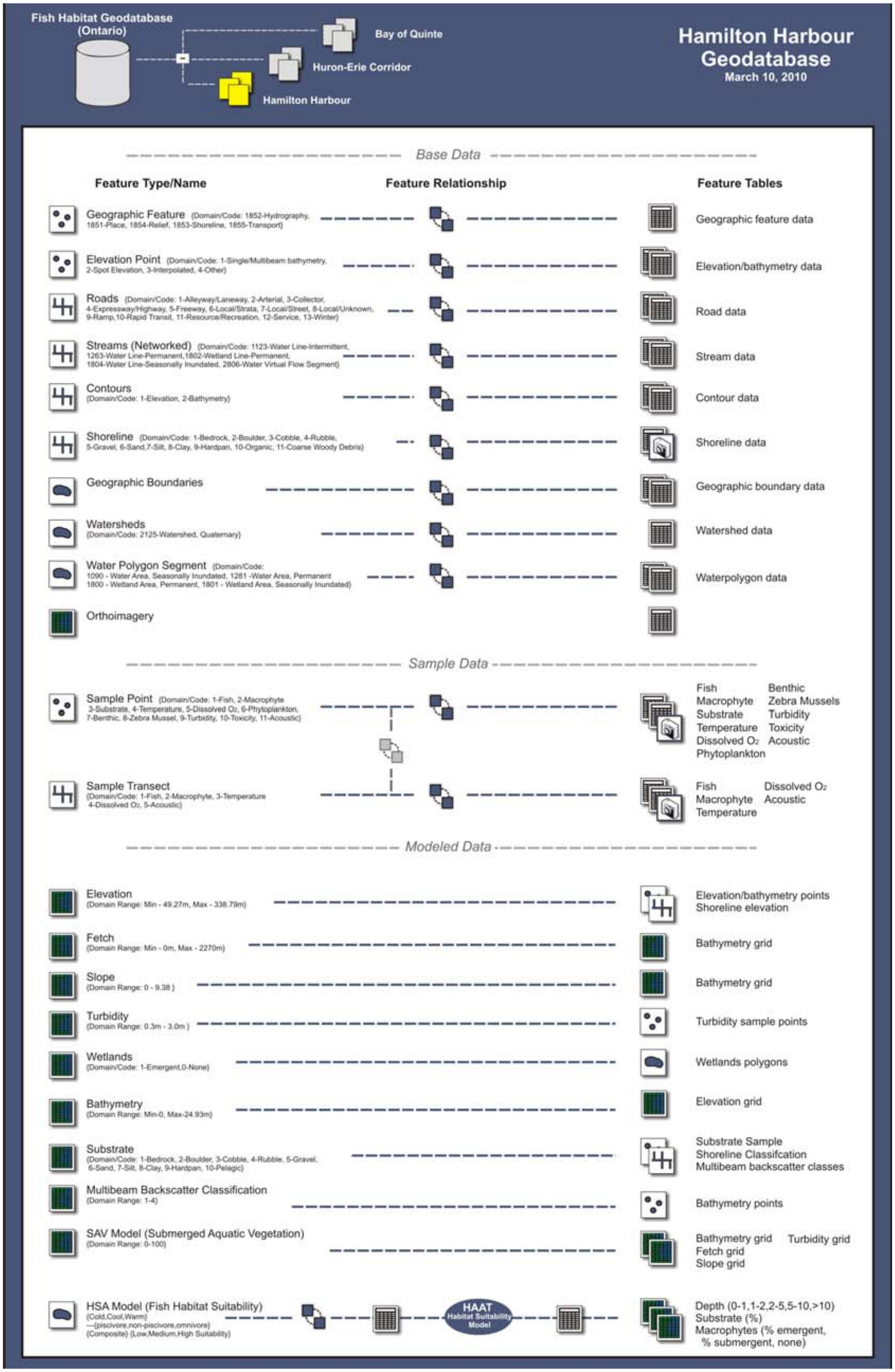

Figure 33. Fish Habitat Data Model.

5.0 DISCUSSION

Hamilton Harbour has been used as a case study to demonstrate a method of integrating spatial information into a data model framework that will assist habitat managers in making informed decisions about fish habitat requirements and delisting targets. This type of data model may be applied to other AOCs, such as the St. Clair River and the Detroit River in the Huron-Erie Corridor. Work has already been completed in the Bay of Quinte (Minns 2008), with the exception of new data to add. The following chart (Figure 34) identifies the status of the work to date:

	Hamilton Harbour			Bay of Quinte			Detroit River			St Clair River		
	Historic	Current	Future	Historic	Current	Future	Historic	Current	Future	Historic	Current	Future
Bathymetry/Elevation	✓	✓	⊘	✓	✓	⊘	⊘	✓	⊘	⊘	✓	⊘
Substrate	✓	✓	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Fetch	✓	✓	⊘	✓	✓	⊘	⊘	✓	⊘	⊘	✓	⊘
Slope	✓	✓	⊘	✓	✓	⊘	⊘	✓	⊘	⊘	✓	⊘
Secchi	⊘	✓	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Aquatic Vegetation	✓	✓	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Fish Habitat Suitability	⊘	✓	⊘	✓	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘

✓	Completed
⊘	In Progress

Figure 34. Status of spatial data compiled and added to the geodatabase.

Much of the data has been collected for the Detroit and St. Clair Rivers. The "In-progress" status is reflected by some of the issues or challenges listed below.

As with any given project, outlining the successes and challenges is beneficial in both the documentation process and also in applying knowledge to new projects as "lessons learned". One of the key successes of the project was the development and compilation of GIS layers needed by DFO researchers that are suitable for use in scientific models, including fish habitat models. Assembled from different sources, these layers represent a synthesis of data that has been collected, and reflects the expertise of the individuals that collect it.

Another key success is the ability to apply the fish habitat framework (concepts and design) for Hamilton Harbour to other areas. This portable approach will streamline the decision-making process (with regards to data requirements) and also facilitate data processing. It will also assist in identifying and anticipating challenges for other AOCs where fish habitat and fish populations are considered to be impaired, particularly with recognizing data gaps.

Applying the concepts and design from this case study will help implement an "area-based" approach to managing resources. This type of comprehensive approach looks at the "management of human activities in a place rather than dividing management according to individual sectoral activities wherever they occur" (Young et al. 2007). In addition, Young states "The boundaries of ecosystems are difficult to define….. the boundaries of governance systems can be distinct (as lines on maps) but often have little to do with the spatial structure of either the biophysical or human dimensions of marine ecosystems." From a Great Lakes' perspective, using a GIS as a tool can assist with integration and spatial understanding of factors influencing ecosystems. The output helps with collaborative planning and adaptive management of resources locally, regionally, and internationally.

A side benefit of this project is the communication between data managers, GIS specialists and research partners. Recalling the stages of data model development, researchers are involved in the design, input and testing of spatial data. With the improvement of technology and the growing need and case for spatial analysis using GIS, this tool is invaluable, especially for area-based management. GIS provides new ways of storing, presenting, analyzing and modeling simple and complex spatial data. The development of a “fish habitat framework” data model allows DFO researchers to share their knowledge, expertise and advice with other stakeholders and managers, particularly, in identifying fish habitat supply (using depth, substrate, vegetation and other data used to develop layers needed for habitat modeling), but also by learning from the various data management and spatial layer creation challenges in the process.

A number of challenges, including project and data-related issues, were noted throughout this document. One in particular was the scope of the project and of the geodatabase. Completion of the geodatabase work was limited to Hamilton Harbour AOC initially, and while significant progress has been made on the other AOCs in terms of data collection and processing, there is still a considerable amount of work to be completed for spatial input and analysis. In Hamilton Harbour, historic and future habitat conditions have yet to be analysed.

Another challenge encountered relates to the data model and representing the complex relationships between the GIS layers in a web environment. Specifically, presenting this information in a web mapping application required a different geodatabase model that is compatible and “web” friendly. The original layers had to be scaled down into a simplified format that could easily be accessed and queried. This approach is much different than structuring the data in a traditional, normalized RDBMS.

Recognizing the nature of the data, and the type of information collected and compiled into the geodatabase, it is often difficult to share with partners due to data sharing constraints and agreements. This does not necessarily restrict access to the interpreted results, but the raw information used to generate some of the GIS layers. While still a challenge, it can often be rectified easily and, depending on the nature of the application or organization, agreements can be made on an ad-hoc basis for sharing.

While data accessibility can often pose a challenge, there are a number of inherent data challenges when using information from external organizations or third parties. It is common that the condition of the data needs to be addressed prior to implementing in an analysis or map display. Specifically:

- formatting: spreadsheets or tables need to be compatible with GIS input format
- georeferencing: identifying the projection and datum to be used/that were used, and aligning with those of the project
- GIS feature type: translating data features into a useful data type (e.g. transect lines into points)

Other notable spatial or data challenges include:

1. *Scale* – all data is not available at the same scale, which dictates the level of detail possible in analysis and layer generation (e.g. national vs. provincial data).
2. *Accuracy* – when more than one temporal dataset is available, one must choose the most appropriate representation of the time period being studied (e.g. historic, current, future shoreline features) or make assumptions.
3. *"Alignment" of related layers* – implications often arise from choices made in (2) with subsequent data collected to fill gaps or new layers created from assumptions based on expert opinion (e.g. bathymetry).
4. *Consistency within a dataset* – lack of standardized classifications and qualitative versus quantitative observations often require interpretation (e.g. substrate).
5. *Data gaps* – where no data exists, proper interpolation methods need to be evaluated and implemented (e.g. SAV).

6. *Cumulative error* – within a dataset/layer – compounded by all the challenges mentioned above it is difficult to quantify uncertainty but this must be considered when evaluating results and using layers for further modeling.

7. *Application* – particularly with other systems and geographic areas, data model and spatial methods may need to be adjusted (e.g. riverine vs. lake including flow modeling/currents).

Identifying and recognizing these challenges is valuable for the GIS analyst and researchers, and will assist in the communication of impacts, gaps and uncertainties and future decisions throughout the course of the project. As with all assessments and models, caveats are necessary to their application and will be stated up front.

6.0 CONCLUSION

The fish habitat data model for Hamilton Harbour is useful for making decisions regarding fish habitat targets. Recognizing some of the challenges can aid in identifying future effort (i.e. gap filling), particularly with data collection in the nearshore zone (1-5 m depth) in the case of Hamilton Harbour. With the standard base layers completed, other potential impacts to fish habitat supply can be examined, including temperature, oxygen and contaminant loading issues in the harbour. Much of this work is on-going, particularly within Hamilton Harbour and Bay of Quinte.

Applying this framework to other AOCs or degraded areas is certainly not trivial, particularly with some of the challenges outlined in this document. Identifying the habitat layers needed is the first goal and certainly not the most difficult step. Under different circumstances, data gaps may exist in each area, and subsequently models must adapt to reflect these changes. On the other hand, new information may exist in these areas, offering new elements to be included in the modeling process. Recognizing the value of a GIS and its ability to present and synthesize information will assist in the management of resources and also the recognition and understanding of ecosystem interactions. A spatial framework for fish habitat information is a building block for defining these relationships.

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The authors would also like to acknowledge Lynn Bouvier and Kathy Leisti (DFO) for their contributions, particularly with the submergent macrophyte model, as well as Terese Herron (CHS) for her assistance with vertical benchmarks and datums.

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9.0 APPENDICES

Appendix 1. Sample records from a Defensible Methods input data file for Hamilton Harbour.

```
;HAMILTON HARBOUR DEFENSIBLE METHODS

*UnitType=Area
*Units=m2

*Order=ID,Area,AreaType,Depth,Substrate,Vegetation
*Proportions=Depth:Z0_1,Z1_2,Z2_5,Z5_10,Z10+
*Proportions=Substrate:Bedrock,Boulder,Cobble,Rubble,Gravel,Sand,Silt,Clay,Hardpan,Pelagic
*Proportions=Vegetation:NoCover,Emergent,Submergent

…
10000,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,35,12,0,0","62,0,38"
10001,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,35,12,0,0","79,0,21"
10002,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,36,11,0,0","85,0,15"
10003,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,40,7,0,0","44,0,56"
10004,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,42,5,0,0","56,0,44"
10005,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,42,5,0,0","77,0,23"
10006,25,UNCH,"0,0,100,0,0","0,0,0,0,2,51,47,0,0,0","45,0,55"
10007,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,23,23,0,0","66,0,34"
10008,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,24,22,0,0","49,0,51"
10009,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,25,21,0,0","61,0,39"
10010,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,25,21,0,0","67,0,33"
10011,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,25,21,0,0","68,0,32"
10012,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,25,21,0,0","70,0,30"
10013,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,26,20,0,0","44,0,56"
10014,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,26,20,0,0","57,0,43"
10015,50,UNCH,"0,0,100,0,0","0,0,0,0,2,52,26,20,0,0","59,0,41"
10016,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,26,20,0,0","72,0,28"
10017,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,26,20,0,0","78,0,22"
10018,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,27,19,0,0","56,0,44"
10019,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,27,19,0,0","57,0,43"
10020,25,UNCH,"0,0,100,0,0","0,0,0,0,2,52,27,19,0,0","59,0,41"
…
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