University of Redlands

**Design for Water Quality Index Mapping Tool for Kuyalnik Liman,
Ukraine**

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

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The report of Anton Sizo is approved.

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August 2010

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Abstract

Design of Water Quality Index Mapping Tool for Kuyalnik Liman, Ukraine

by
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Kuyalnik Salt Lake (local name - Kuyalnik Liman) is of great importance for Ukraine because of its recreational and natural resources (medicinal mud and mineral water) and balneology spa network.

Because of its location near a large industrial and port city, the liman is under permanent anthropogenic influence that negatively impacts the fragile ecosystem of Kuyalnik Liman as well as the neighboring area. Because of the significance of the liman for Ukraine, it requires continual environmental monitoring of the liman area including monitoring its water quality.

This project designed and implemented a set of tools for water quality mapping based on the hydro-chemical index of water pollution. It combined both processing the data from water sample analysis with methods of spatial analysis for the lake. This tool will serve to help specialists in the environmental monitoring of Kuyalnik Liman area.

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List of Acronyms and Definitions

WQI	Water quality index
GIS	Geographic information system
DEM	Digital elevation model
IDW	Inverse distance weighted
SWAT	Soil and Water Assessment Tool
MPC	Maximum permissible concentrations
BES	Baltic Elevation System
GUI	Graphical user interface

Chapter 1 – Introduction

Kuyalnik Liman is an inland salt lake located in the south of Ukraine. The liman is the largest source of unique medicinal sulfide-silt mud, mineral water, and chloride-hydrocarbonate-sodic-magnesium healing brine. Because the liman is economically important to the country, permanent environmental monitoring of the Kuyalnik Liman area is required, which includes monitoring water quality.

The client's department, as a representative of the public research institution, is responsible for monitoring environmental changes in the Kuyalnik Liman area. The calculation of the water quality index (WQI) is part of the environmental assessment of the current condition of the liman. The client needs a geographical information system (GIS) to automate the WQI calculation process.

1.1 Client

The client for this project was Shikhaleeva Galina, Head of The Environment Monitoring Department, from the Institute of Physics and Chemistry for Environment and Human Protection.

The main activities of the Environmental Monitoring Department include addressing environmental pollution issues (in air and water, soil and plants), writing white papers for governmental organizations on environmental topics, supporting public organizations in decision making in environmental management, and conducting education and research activities.

The Environmental Monitoring Department, as a representative of the institution, conducts the public project "Complex Environmental Assessment of Natural Resource and Recreation Potential of the Basin of Kuyalnik Liman". For this project, the client is responsible for monitoring environmental changes in the area of Kuyalnik Liman. Annual and seasonal reports, as well as occasional white papers, require the client to calculate the WQI, and to produce charts illustrating the current environmental condition of Kuyalnik Liman. The client needed a GIS tool to automate the WQI calculation process and to map the WQI spatial distribution.

1.2 Problem Statement

The client needed a GIS solution that could support the environmental monitoring process of Kuyalnik Liman in terms of mapping of water quality.

The client wanted a WQI tool that automates the routine calculation of WQI and provides a map of the spatial distribution of WQI through the liman area. The shoreline of the resulting raster should show the water level for the research time period of WQI calculation.

The method should be applicable to the area of interest, and should spread to the academic and administrative communities in Ukraine.

1.3 Proposed Solution

This chapter describes the design of the WQI mapping tool for GIS support of the Environment Monitoring Department for the project of environmental assessment of Kuyalnik Liman. It shows the principal scheme of the WQI tool and the necessary data.

1.3.1 Goals and Objectives

The client needed GIS support to automate the WQI calculation process and to map the WQI spatial distribution. The strategic steps for the project were: to define the method of WQI calculation; implement the method in the GIS procedure; and produce a map of the WQI.

The challenging issue with the first step was to define methodology for the WQI calculation. Different methods entail the use of different scales of water quality. These results can cause confusion in preparing white papers and may cause a mistake in a decision-making process. So, space and time analyses that are based on different kinds of water quality assessment might be wrong. Choosing one appropriate method for the area of research, and its implementation as a GIS procedure, will allow the client to avoid routine manual calculation of the WQI, and will use a standard system for data collection that serves as a foundation for decision making.

The second issue has to do with data manipulation. The client wanted to present the current water quality of Kuyalnik Liman as a raster dataset. The client needed raster data for spatial analysis. It was very important to choose an appropriate method of WQI interpolation for the irregular network of the water monitoring stations. Since the Kuyalnik Liman is a shallow water body that greatly depends on rain and snowfall levels, it is necessary to consider that Kuyalnik's water level changes significantly within the course of a year.

1.3.2 Scope

The project implementation included four principal sections: the calculation of the water quality index (WQI), the mapping of the spatial distribution of the WQI, data preparation, and database design.

The project involved the use of a standard method of calculation. A needs assessment was conducted to determine which methodology to use, how to use and organize a geodatabase (the results of water analysis, the data about place and time of water sampling, the data of the water level). Spatial mapping of the WQI was based on bathymetry data of Kuyalnik Liman and the location of water sampling stations.

1.3.3 Methods

The chosen WQI calculation methodology compares the maximum permissible concentration of pollutants and the current concentration of pollution in the water body (State Committee of Hydrometeorology of the USSR (1986)).

To implement the WQI calculation within a GIS, a geodatabase was designed to contain the water analysis results table and the location of the water monitoring stations. For these purposes a list of pollutants, possible ranges of concentrations, and the layer

with the disposition of the water monitoring stations were used. The methodology of the WQI calculation mentioned above gave formulas for calculation. Python was used as a programming and scripting language in the ArcGIS environment.

The change of the liman water level was shown in the raster of the WQI spatial distribution as a shoreline. This required using the Spatial Analysis tools and bathymetry data of the Kuyalnik Liman bottom.

The inverse distance weighted (IDW) interpolation method was chosen as an appropriate method for estimating the WQI for the irregular network of water monitoring stations. The IDW interpolation was proposed to and approved by the client.

1.4 Audience

This report was prepared for an audience qualified in the environment monitoring sphere, well educated (no less than Bachelor or Specialist degree in natural science), preferably with experience in chemical or environmental field and with a basis in statistic analysis. The audience should be experienced in GIS software at no less than at user level.

The audience might also include personnel from environmental or chemical laboratories, students or professors from academic institutions affiliated to natural sciences or studies, and employees of NGO's or public organizations who are involved in environmental management.

1.5 Overview of the Rest of this Report

Chapter 2 will provide information about the general context of Kuyalnik Liman and the bordering area. Also there are the basis of the report problem and an overview of existing similar situations and implemented solutions: different approaches in WQI calculation and GIS applications for water quality, etc.

Chapter 3 describes the project system analysis and design. There are functional and technical requirements for the WQI tool implementation at workplace, operational and transitional requirements for tool maintenance and installment for workflow.

Chapter 4 describes all database design decisions that were made during the project: conceptual and logical models of support geodatabase of water sampling and the WQI tool; description of data source of maps for bathymetry data of Kuyalnik Liman and methods of map and table data preparation.

Chapter 5 discusses the project implementation. It answers the question "How was it created?" through the Python code and ArcGIS geoprocessing.

The project results discussion and analysis are in Chapter 6; answers for the questions: "Did the client get what he wants?", "Was the project implemented as it was planned?", "Was it challenging?".

Chapter 7 shows connection between implemented project and future plans and opportunities. Different water quality methods that could be realized, environment of the WQI tool implementation, and such other topics are discussed there.

Chapter 2 – Background and Literature Review

The geographic disposition of Kuyalnik Liman and its morphological features make the environmental conditions of this lake highly dependent on climate and anthropogenic impact. This situation raises a question about permanent environmental monitoring, methods and approaches appropriate to environmental assessment of the liman. GIS framework provides an adequate basis for data analysis and processing, and WQI gives a method for relevant rating of the liman's water quality.

2.1 Kuyalnik Liman

Kuyalnik Salt Lake (locally - Kuyalnik Liman) is located in the south of Ukraine (Figure 2-1) and is affiliated with a group of northwest Black Sea littoral limans.

Figure 2-1: The location of Kuyalnik Liman.

The watershed area of Kuyalnik Liman is 2250 square km. The morphological parameters are highly dependent on annual precipitation, but on average the water area is 56 square km, the length is 25 km, the width is 2.2 km and the depth may reach 4.5 m (Timchenko, 1990).

The main resources drawn from Kuyalnik Liman are 23848 thousand cubic meters of medicinal sulfide-silt mud, 1385 cubic meters per day of mineral water (Cabinet of

Ministry of Ukraine, 1996), and up to 112 million cubic meters of chloride-hydrocarbonate-sodic-magnesium healing brine in the bowl of the liman.

Kuyalnik Liman is situated near the city of Odessa (population one million) with a broad network of balneological spas. The oldest spa has been there for about 170 years. The unique location of Kuyalnik Liman – its proximity to the Black Sea, sandy beaches, and healthy prairie air – make the region around Kuyalnik Liman a significant balneological health resort with unique natural conditions.

Kuyalnik Liman is a water body with a limited water cycle, and it is significantly impacted by human activities in the city of Odessa. The shallow depth and long length of the liman also make it sensitive to the climatic condition of the region, hydrological conditions, and water quality.

Because of its importance to Ukraine, permanent environmental monitoring of the area of Kuyalnik Liman is required, which includes the monitoring of water quality and keeping different parties informed (Figure 2-2).

Figure 2-2: Main consumers of the water quality information.

Processed by the client, the environmental monitoring scheme is seasonally based. The locations of the water sampling stations are irregular through the liman area (Figure 2-3).

The client, as the research institution, is responsible for monitoring environmental changes in the area of Kuyalnik Liman. Annual and seasonal reports, as well as occasional white papers, require the client to manually calculate the WQI and present the current condition of Kuyalnik Liman with charts. The client wanted to avoid manual

routine calculation of WQI and create a mechanism to present the distribution of WQI in a spatial continuum with ability to use the data for spatial and temporal analysis.

Figure 2-3: The water sampling station network.

2.2 WQI Approach

Nature conservation organizations, both administrative and research oriented, use various approaches to calculate WQI. The quality index calculation method depends mainly on state affiliation, geographic location of water bodies, type of water use, chemical, and biological factors. Therefore, the determination of WQI calculation is crucial in mapping water quality for a specific water body.

The Canadian Council of Ministers of the Environment (2001) and Stoner (1978), described the main purposes of using WQI: to unify the rating scale of natural water by using the meaningful water range from “very bad” to “very good”, and for understanding of the water quality topics by non-specialists. Proposed by the Canadian Council of Ministers of the Environment (2001), the universal method of WQI calculation is based on three attributes of water quality: proportion of guideline values exceeded, frequency

with which guideline values are exceeded, and magnitude by which guideline values are exceeded. These all depend on the levels of several parameters.

Cude (2001) proposed a method of WQI calculation, applicable for certain carefully studied water objects. In his case, it is a method used by the state of Oregon in the US. He recorded values for eight measureable variables of water quality when they were beyond a certain range: temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia + nitrate nitrogen, total phosphorus, total solids, and fecal coliform. A similar method was also used by Hambright et al. (2000). However, their selected variables and ranges are only applicable for Lake Kinneret (Sea of Galilee), Israel.

A wide range of methods for WQI calculation have been inherited from soviet research institutions in the countries of the former Soviet Republic. Shitiokov et al. (2003) proposed several methods of WQI calculation based on hydro-chemical variables of assessment of water quality, such as:

- Parameter of chemical water pollution, calculated on the basis exceeding limits of 10 water parameters
- Combinatorial index of pollution, based on limits exceeding, multiplicity and its frequency
- Method from the Science Research Institution for Hygiene of F.F. Erisman, that takes into account exceeding levels of chemical, microbe, and organoleptic parameters

Currently, the commonly used method of WQI determination in Ukraine is the method proposed by State Committee of Hydrometeorology of the USSR (1986). It represents an average fraction of limits exceeding six parameters. These might be water parameters: biological oxygen demand, O₂, pH and/or pollutants that are specific for study area. Because of their applicability to Kuyalnik Liman and popularity in Ukraine, this method was chosen as the theoretical base for this project.

2.3 Water Quality Modeling and GIS Framework in Environmental Assessment

Water quality modeling is a way to obtain information in case of lack of data, impossibility for direct research, or for forecasting. For example, the Federal Maritime and Hydrographic Agency of Germany routinely used a model of the condition of the North and Baltic Seas. The model considered water level, temperature, and salinity (Wright et al., 2007). The United States Environmental Protection Agency (2009) proposed different kinds of tools and models for various environmental issues, including schemas for water quality modeling: Water Quality Analysis Simulation Program v.7 (WASP7) and River and Stream Water Quality Model (QUAL2K).

In any case, any model requires an environment of implementation. And very often GIS serve not only as platforms for model development, but also as analysis and performance toolsets for spatial data. The ArcHydro Data Model for ArcGIS may serve as example. It is a spatial-temporal model for water resources, focusing on the modeling of the hydrological process of surface water and on hydrography. It includes components such as: network, drainage, channel, hydrography, and time series (Maidment, 2002). It requires customization based on the area of interest. Another example, Srinivasan et al. (1993) connected a tool kit for environmental pollution modeling Soil and Water

Assessment Tool (SWAT) with OpenSource GIS. The system assists with management of runoff, erosion, pesticide, and nutrient movement in large scale basins. Zhang (2008) designed a GIS system that is a dynamic-based model which allows users to track water quality changes in rivers in one dimension for water pollution accidents. However, models and tools of water modeling are often designed for a specific water object or particular problem.

Kurakina et al. (2006) used the ArcGIS 9.1 environment for issue similar to the current project: they used Model Builder to create a tool for a WQI calculation for section of a river between water quality checkpoints. In this work, the authors also demonstrated using geo statistical methods for selection of method of interpolation.

Widely known ArcGIS 9.3.1 ESRI software was used for the current project as the environment for data store and transformation, as well as for the scripting environment. Python was selected as OpenSource language for coding.

2.4 Summary

Using GIS to address environmental issues is not a new approach. It has been widely used in the context of monitoring water quality. Essentially, water quality can be evaluated based on a water quality index that takes various forms. Using the WQI approach, water quality can be further modeled in a GIS platform.

For the current project the method of WQI calculation proposed by State Committee of Hydrometeorology of the USSR (1986) was used. ESRI ArcGIS 9.3.1 software was chosen as the GIS environment for tool development.

Chapter 3 – Systems Analysis and Design

3.1 Problem Statement

The client for this project was Shikhaleeva Galina, Head of The Environmental Monitoring Department, from the Institute of Physics and Chemistry for Environment and Human Protection.

Kuyalnik Liman is a coastal salt lake located in the south of Ukraine. The liman is the source of medicinal sulfide-silt mud, mineral water, and chloride-hydrocarbonate-sodic-magnesium healing brine. Because the liman is important to the country, the permanent environment monitoring of the area of the Kuyalnik Liman is required, which includes monitoring water quality of the liman.

The public research institution that the client is affiliated with is responsible for monitoring environmental changes in the area of Kuyalnik Liman. Annual and seasonal reports, as well as occasional white papers, require calculation by the client of WQI and the presentation of the current condition of the Kuyalnik Liman by charts. The client wanted to avoid manual routine calculation of WQI and needed a mechanism to present the distribution of WQI in a spatial continuum with ability to use the data for spatial and temporal analysis.

3.2 Requirements Analysis

3.2.1 Functional Requirements

The WQI mapping tool was developed for a research staff workplace. It is assumed that research personnel will use the WQI mapping tool for their workflow needs, in addition to current GIS software. The tool is designed for desktop operation, with user access to change data and save the result of his work.

3.2.2 Technical Requirements

The developed mapping tool works only in the ArcGIS environment. It is assumed that the user has valid ArcGIS Desktop and Spatial Analysis licenses (version 9.3). All necessary GIS data processing, data format exchanges, and updates are handled by ArcGIS software.

Hardware requirements:

Platform	PC, Intel recommended
CPU Speed	1.6 GHz recommended or higher
Processor	Intel Core Duo, Pentium 4 or Xeon processors recommended
Memory/RAM	1 GB minimum, 2 GB recommended or higher.
Display Properties	24 bit color depth
Screen Resolution	1024 x 768 recommended or higher at Normal size (96dpi)
Swap Space	Determined by the operating system, 500 MB minimum.
Disk Space	2.4 GB (at least 10 GB in case printing large maps)
Video/Graphics Adapter	24-bit capable graphics accelerator. An OpenGL 1.3 or higher compliant video card is

	required, with at least 32 MB of video memory, however 64 MB of video memory or higher is recommended.
Networking Hardware	Simple TCP/IP, Network Card or Microsoft Loopback Adapter is required for the License Manager.
Media Player	DVD-ROM drive is required to install the application.

Software requirements:

- Windows Help program (WinHlp32.exe)
- .NET Framework 2.0 Requirement
- Internet Explorer (Version 7.0 or 8.0)
- Python
- Printer Support

3.2.3 Operational Requirements

The WQI mapping tool was supplied as a once-only delivery, as a ready-to-go tool. In the event of malfunctions, the information and developmental support is provided until the tool meets all requirements.

In case all technical requirements are met, there is no need for any additional maintenance for the tool. The ability of batch processing is included in the ArcGIS tool's features.

3.2.4 Transitional Requirements

The client's research personnel are highly qualified and well educated. They are used to working with complex data analysis software, and they have the necessary experience in the GIS field. Entrance training for this project was provided after the project was delivered.

The mapping tool was presented as an additional tool for research; minor changes of current client's workflow were implemented. To facilitate the alterations, the detailed description of changes in the business process was highlighted with instructor-led workshops. The migration from the previous workflow to the new one was also simplified by the complete tool technical help documentation that was the part of the delivery.

3.3 System Design

The calculation of WQI mapping tool was based on the method proposed by State Committee of Hydrometeorology of the USSR (1986). The parameters of water were obtained from laboratory analysis of samples from the water monitoring stations network of Kuyalnik Liman.

The WQI mapping tool was intended for use in ArcMap or ArcCatalog environment as a toolset. The output of the introduced tool was a map of the water quality index distribution in ArcGIS raster format, with possible use with any kind of map data presentation and analysis supported by ArcGIS.

3.3.1 Map

The output map of the project tool was in digital format (ESRI grid raster dataset) and showed spatial distribution of the WQI through the Kuyalnik Liman area. The calculation methodology was proposed by State Committee of Hydrometeorology of the USSR (1986). The outline of the water quality raster reproduced the shape of the water body, based on the current water level (see Figure 3.1, year: 2008, water level: -5.33 m in Baltic Elevation System (BES))

Figure 3-1: Water quality index raster of Kuyalnik Liman

For a support of map classification, the reference layer with symbology was included in the delivery. The layer divided the WQI raster into seven gradations of water quality:

Water quality	Class of water quality
Very clean	I
Clean	II
Moderately impure	III
Impure	IV
Polluted	V
Very polluted	VI
Extremely polluted	VII

Reference layer was represented in a color scheme, corresponding to the meaning of water quality differentiation: clean water was represented in positive colors (e.g. hues of

green), polluted and impure water were represented in negative colors (e.g. hues of red), (Figure 3.2; pH, O₂, Pb, Cd, Cr, Nitrites were used for WQI calculation with MPC's from Euro Union water standards).

Figure 3-2: The layers of water quality of Kuyalnik Liman

3.3.2 Technology

The main part of the project delivery was represented as an ESRI ArcToolbox element. The user may work with the tool both from ArcMap and ArcCatalog environment. A graphic user interface (GUI) was designed by regular ArcGIS GUI form for geoprocessing tools (Figure 3.3).

The use of a regular ArcGIS GUI as a water quality index mapping tool lets the user be more familiar with the processes of tool operation. Included tool help assists the user in aspects of tool use.

Figure 3-3: GUI window for the water quality index tool

The result of tool work was a raster that represents water quality spatial distribution. The combination with symbology reference ArcGIS layer brings high flexibility in the use of obtained data. It is possible to use the map with any kind of background map data supported by ArcGIS.

3.3.3 System architecture

The client's research personnel (users) are highly qualified and well educated for work with complex data analysis and GIS software in the environmental field. The WQI mapping tool was developed for research purposes for individual desktop operation, giving the user access to change data.

All necessary GIS data processing and data format exchanges are handled by ArcGIS software.

The WQI mapping toolbox contains Python script for the following three basic sub processes: the calculation of shoreline of current water level, WQI calculation, and data interpolation. The elements of the system are described below:

- WQI calculation subtool calculates WQI data for the water sampling stations.
- Water samples results table is the data of laboratory water samples results. The data include: date of water sampling, name of the water sampling station and list of measured pollutants with its concentration.
- Water sample station disposition includes a layer with the disposition of the water sampling stations with attribute data including: name of the water sampling station, type of the water sampling station (inside or outside of the water body) and affiliation to the zone of the water body.
- The Shoreline calculation subtool creates Shoreline based on the current value of the water level. DEM element uses data of the depth of the water body.
- Current water level data regarding the water level of the water body.
- WQI interpolation subtool is used for the WQI interpolation. It generates data of the distribution of WQI through the water pond's area (WQI raster).

Figure 3.4 demonstrates the relationships between hardware, software, processes, data, and user sections.

Figure 3-4: The workflow

3.4 Project Plan

3.4.1 Challenges

From the start of the project evaluation there were not any significant changes of project theme. From beginning to end the schema of project implementation just became more detailed and ways of implementation became clarified.

Only one point of the project was implementation changed, but only because of functionality limitations of ArcGIS geoprocessor 9.3.1 for Python. It was a transfer of a symbology from a reference layer to the output WQI raster. In case of software upgrade in ArcGIS 10 this feature will be implemented.

The client was also interested in a Web resource of data processing and presentation. It was not a mandatory condition, but it was preferable to fulfill the project by representing both desktop and web tools.

3.4.2 Budget

There were several main cost items for project implementation (from high to low): software, training, and hardware; data and data processing; and cost of time for tool design and development.

The software, training and hardware costs were separated between the developer and the client. The client already had the necessary software environment (ArcGIS) and his hardware satisfied project implementation requirements.

The entrance trainings for the client personnel was organized as instructor-led workshops and the help documentation were the part of the project delivery.

The data for the project was the client's property and was provided at no cost.

3.4.3 Deliverables

The delivery of the project consisted of: the WQI tool as a Python script for the ArcGIS Environment (as an ArcGIS Toolbox), a geodatabase with the project data scheme, the technical documentation of the tool and an instructor-led workshop for the client personnel. The media for the data delivery was CD/DVD.

3.4.4 Risks

The riskiest aspects of the current project were: the bathymetry data, the data processing, the project management issue, and the issue of the client's business process changes.

The bathymetry data were old and mostly paper based; the data processing required several steps of preparation: careful digitizing of the data, data georeferencing, and data processing using different methods of interpolation, etc. All these steps, including the general low accuracy of the old paper data, reduced the accuracy of the whole project.

As the current project was small-scale with a limited scope for the management issue, the response for the problem was a close collaboration and step-by-step workflow discussion with executive personnel from the client's side.

There was an issue of the business process change, including the problem of customization and the minor changes in the business process within the client's organization. There were two solutions as a response plan: the detailed help documentation of the tool was prepared as part of the project delivery, and the description of the changes in the business process were taught during the instructor-led workshop.

3.5 Summary

The client for this project was Shikhaleeva Galina, Head of the Environment Monitoring Department, affiliated with the Institute of Physics and Chemistry for Environment and Human Protection. The client was responsible for monitoring environmental conditions of Kuyalnik Liman and needed GIS support to automate the water quality index (WQI) calculation process and to map the WQI spatial distribution. The calculation of the WQI was based on the exceeding of the maximum permitted concentrations of the pollutants.

The water quality index (WQI) mapping tool was developed as a desktop utility for a research staff workplace. It works under ArcGIS environment on PC platform computers.

The tool delivery included the tool with help documentation, operation manuals, and instructor-led workshop. The informational support was provided in case of mapping tool malfunction.

The riskiest aspects of the current project were: the data and data processing, the project management issue and the issue, of business process change. The migration from the old to the new workflow in the client's organization will be fully supported by training for client's personnel. The methodology for the data processing is correct for any data with higher accuracy.

Chapter 4 – Database Design

The concept of the database design used in this project was built on a database structure provided by the client. The main objective of the project's database was to support the client's activity in environmental monitoring of Kuyalnik Liman in terms of water quality assessment using the WQI tool.

For this purpose the database contains such main classes as: water parameters that are obtained from laboratory sample analyses; water monitoring (sampling) stations that are distributed through the area of water body and the bathymetry data of Kuyalnik Liman for marking changes of shoreline of the water body.

4.1 Conceptual Database Design

There were several classes in the database that served as a data resource for the WQI calculation, according the method establish by State Committee of Hydrometeorology of the USSR (1986) described below (Figure 4-1):

- water samples results – a table with data of laboratory analyses of samples, collected through water body area. This table provides pollutant concentrations and some additions water parameters.
- water sample station disposition – feature class of the water monitoring station location through the water body.
- DEM – digital elevation model (bathymetry data) of bottom of a water body. It serves for shoreline calculation.
- mpc (maximum permissible concentration) – optional table with data of maximum allowable content of pollutants for different types of water use.
- Points2Water – the class of relationship between two tables, based on unique names of water monitoring stations.

Several domains were used in the database to avoid a misspelling of entering data. Presented in the database coded values domains are the legal values of fields for several classes:

- Month – list of months in year
- Season – list of seasons in year
- Pointkind – coded values that point to affiliation of water sampling station to area of water body or to water network
- Zone - coded values that point to affiliation of water sampling stations to specific zone of water body or to water network
- Type of water use (type_wat_use) – coded values that set MPC on the basis of type of water use of water body
- Issued agency (iss_agency) – publisher of MPC

Figure 4-1: The database conceptual design.

4.2 Database Implementation

The implementation of the project database was made on the basis of ESRI File Geodatabase. This choice based on two reasons: the client's needs and necessity of project technology.

The client required a desktop solution for storing geographic and table data compatible with ESRI ArcGIS software. An ESRI File Geodatabase format was chosen as a fast, high performance solution for a single user or small group. This format also meets other project requirements such as: storing rasters in the geodatabase and improved locking schema (Childs, 2009).

There were several main segments in the project database: classes (tables and feature classes), domains, relationships, and the raster dataset. All spatial data were stored in a WGS 1984 UTM Zone 36N projection.

The classes consisted of two tables and one feature class:

- Table of water samples parameters. It contains results of laboratory analyses of water samples. The parameters from this table are used as input data for WQI assessment. The table has three domains: two temporal (month and season) and one that serves to point to monitoring station affiliation (pointkind) (Appendix A, Table A-1).
- Table of maximum permissible concentrations (MPC) for water resource; it also contains two service fields that help filter MPC by type of water use and by publisher (values for these fields are stored in domains). The MPC values serve as limit parameters for WQI calculations (Appendix A, Table A-2).

- Feature class of water monitoring stations, Figure 2-3 in Chapter 2. Serves for calculation of spatial distribution of water parameters, also has two domains: one that serves to point to monitoring station affiliation (pointkind) and a second which serves for zone of water body marking (zone) (Appendix A, Table A-3).

Domains in the project geodatabase table were represented by coded value domain type. They are listed in Appendix A, Table A-4.

The semantic connection between the water samples parameters class and water monitoring stations class in the geodatabase was represented by relationship class Points2Water. It managed the associations between data affiliation to monitoring stations in one class and the monitoring stations dispositions in another. The description of the relationship class Points2Water is given in Appendix A, Table A-5.

The raster that represented the bathymetry of Kuyalnik Liman - DEM - was stored in the geodatabase as an ESRI Grid Raster Dataset. The measurement unit of this class was the meter in Baltic Elevation System (BES). Table A-6 from Appendix A illustrates this specification.

4.3 Data Sources and Data Collection Methods

The data used for the project implementation were provided by the client. However, it is necessary to give an idea of the data source that is served as a part of the project.

The water samples parameters table contained results of water sample analyses. The methods of these analyses and their precision varied, depended on the parameter and did not set in the database. The number and list of research parameters and methods are part of the accreditation of the laboratory and may change from one accreditation to another.

The water monitoring stations feature class located the disposition of water sampling stations. The disposition data were collected by handheld Garmin GPS12 and Garmin GPSMAP60 during the field work.

The bathymetry data of Kuyalnik Liman was based on data of a field survey that was conducted by the Ukrainian Research Institution of Balneology in 1975. The four paper maps from the report of UkrRIbalneology (1975) represented the network of depth measurements of Kuyalnik Liman. The maps contained the point data with elevation marked in BES and three isolines of depth in BES of the Kuyalnik Liman. For example, Figure 4-2 shows map of the northern part of Kuyalnik Liman.

0.0000000001. These changes allowed the user to query the analysis data for meaningful results with the statement [> 0].

There were several steps for the bathymetry data processing. The scanned paper maps were georeferenced in WGS 1984 UTM Zone 36N projection on the basis of the Landsat remote satellite imagery. From the digitizing of the georeferenced maps were obtained: feature class of points with depth values in Baltic Elevation System (BES) and feature class of isolines of depth of Kuyalnik Liman with marks: -4.7, -5.0 and -6.0 meters in BES (Figure 4-3).

Figure 4-3: The data for the bathymetry data processing.

Topo to Raster was chosen as the method for the bathymetry data raster creation from the ESRI Spatial Analyst toolbox as a method that provides hydrographically correct relief (ESRI, 2010).

4.5 Summary

The design for the project database was inherited from the database structure provided by the client. The database contained the classes: water parameters that are obtained from laboratory sample analyses; water monitoring stations that are distributed through the area of a water body, and bathymetry data of Kuyalnik Liman for marking the changes of shoreline.

Several domains were used in the database. Presented coded values domains were the legal values of fields for several classes: Month – list of months in year, Season – list of seasons in year; Pointkind – coded values that point to affiliation of water sampling stations to area of water body or to water network; Zone – coded values that point to affiliation of water sampling stations to a specific zone of water body or to water network; Type of water use – coded values that mark MPC on the basis of type of water use of water body and Issued agency – publisher of MPC. All spatial data are stored in a WGS 1984 UTM Zone 36N projection.

The semantic connection between water samples parameters class and water monitoring stations class in the geodatabase was represented by relationship class Points2Water.

The data used for the project implementation were provided by the client. The data of disposition of water monitoring stations were collected by handheld Garmin GPS12 and Garmin GPSMAP60 during the field work. The bathymetry data of Kuyalnik Liman were based on paper maps from a field survey that was conducted by Ukrainian Research Institution of Balneology in 1975. Topo to Raster tool was chosen as a method for the bathymetry data creation that provides hydrographically correct relief.

Chapter 5 – Implementation

As mentioned in previous chapters, the implementation of the project was based on the methodology of a water quality index (WQI) calculation proposed by State Committee of Hydrometeorology of the USSR (1986) within a Python and ArcGIS geoprocessing framework.

The first part of this chapter describes the method of the WQI calculation; the second part details Python code implementation and using of ArcGIS geoprocess tools.

5.1 The Method of WQI calculation

The WQI used for this project is the hydro-chemical index of water pollution proposed by State Committee of Hydrometeorology of the USSR (1986). It is widely used throughout the territory of the former Soviet Union countries as the method for assessment of water quality for water ponds; the copy of methodology in original (Russian) language is given in Appendix C.

This index is typical additive coefficient and represents average contribution of maximum permissible concentrations (MPC) exceeding on the basis of limited water ingredients (water parameters and pollutants).

The formula for the WQI calculation is:

$$WQI = \frac{1}{n} \sum_{i=1}^n \frac{C_i}{MPC_i} \quad (5.1)$$

Where:

- C_i = concentration (value) of water ingredient (water parameters and (or) pollutants)
- n = number of water ingredients (water parameters and (or) pollutants)
- MPC_i = maximum permissible concentration for this type of water use

The WQI calculates for different numbers of water parameters and pollutants, including pH value, biochemical oxygen demand and dissolved oxygen. For this it is necessary to calculate the ratio C_i/MPC_i . The WQI is calculated on the basis of six parameters.

There are several rules for the WQI calculation for some standardized water parameters:

- There are special norms for a biochemical oxygen demand that depends on current the value of the parameter, Figure 5-1.

Figure 5-1: MPC relationship to biochemical oxygen demand level.

- There are ratio C_i/MPC_i values that depend on dissolved oxygen value, Figure 5-2.

Figure 5-2: C_i/MPC_i relationship to dissolved oxygen level.

- There is a limit of 6.5 to 8.5 for a pH values for water ponds. So the ratio C_i/MPC_i values depend on exceeding of this limit, Figure 5-3.

Figure 5-3: C_i/MPC_i relationship to pH level.

There is a class division on the basis on the calculated WQI value:

Table 1. The water quality classes.

Water purity	WQI value	Water quality class
Very clean	less than 0.2	I
Clean	0.2 – 1.0	II
Moderately impure	1.0 – 2.0	III
Impure	2.0 – 4.0	IV
Polluted	4.0 – 6.0	V
Very polluted	6.0 – 10.0	VI
Extremely polluted	more than 10.0	VII

There is a requirement that the WQI be compared only for water body of same biogeochemical province and similar type; for the same water body or waterway and with a consideration of water content of current year. In case of this project these requirements were met.

5.2 Workflow of the WQI calculation

Below is the description of use of ArcGIS geoprocessing tools and variables through the algorithm of the WQI calculation. The detailed Python code listing is provided. The algorithm is described in Figure 5-4 by main functions. The full listing of Python code is provided in Appendix B. Figure 3.3 in Chapter 3 shows the full view of the tool's GUI in ArcGIS environment.

Figure 5-4: The algorithm of the WQI tool by main functions.

There were several required service variables that help correct ArcGIS geoprocess tools running (the input view is shown at Figure 5-5):

- Temp folder variable – the temporary folder for data that are created during the tool running. The ArcGIS GUI data type of Temp folder variable is Folder.
- Coordinate system variable – the coordinate system for a study area. To avoid potential errors it is highly recommended to reproject all input data to one coordinate system before tool use. The ArcGIS GUI data type of Coordinate system variable is Coordinate system.

- Cell size for output raster – the cell size for result water quality index raster in the previously input coordinate system units. The ArcGIS GUI data type of Cell size for output raster variable is Long (long integer).
- Output folder – the folder for the output water quality index raster. The ArcGIS GUI data type of Output folder variable is Folder.

Figure 5-5: The service variable input tool GUI.

The Python code for input of these variables:

```
# Setup temp and scratch folders
TempFolder = gp.GetParameterAsText(0)
gp.ScratchWorkspace = TempFolder
# Enter coordinate system from ArcGIS GUI
CoordSystem = gp.GetParameterAsText(1)
gp.CartographicCoordinateSystem = CoordSystem
CellSize = str(gp.GetParameterAsText(2)) # cell size for output raster
OutputFolder = gp.GetParameterAsText(3)
```

The main input data for the WQI calculation was represented by several mandatory datasets.

Water sample table was the input tabled data of laboratory water samples results (list of measured pollutants with their concentration). The mandatory service fields for this table for the WQI calculation were: year for sampling year, season for sampling season, pointkind for a sample affiliation: to water area of water body (a) or to water network (w), n_point as a name of the water sampling station.

Sample stations was the feature layer with the disposition of the water sampling stations with their attribute data. The mandatory service field of this feature class for the WQI calculation was n_point as a name of the water sampling station.

For the WQI calculation it was necessary to take six water pollutants and/or water parameters. The inputs of the first three pollutants were combined with the ability to choose one of three water parameters that might be taken into account in the WQI calculation: biochemical oxygen demand, dissolved oxygen, and pH. So there were several service fields for choosing type of input value: regular pollutant or one from three water parameters. The input has the choice of biochemical oxygen demand, dissolved oxygen, and pH. In case for choosing any of water parameter instead pollutant the “MPC for Pollutant ...” fields should be left blank. Otherwise the MPC value should be entered for each pollutant.

The input view for the main input data is shown in Figure 5-6

Water sample table

Sample stations

Biochemical oxygen demand or Pollutant type

Biochemical oxygen demand or Pollutant field

MPC for Pollutant or Cancel for Biochemical oxygen demand (optional)

Dissolved oxygen or Pollutant type

Dissolved oxygen or Pollutant field

MPC for Pollutant or Cancel for Dissolved oxygen (optional)

pH or Pollutant type

pH or Pollutant field

MPC for Pollutant or Cancel for pH (optional)

Pollutant 1 field

MPC for Pollutant 1

Pollutant 2 field

MPC for Pollutant 2

Pollutant 3 field

MPC for Pollutant 3

Figure 5-6: The main data input tool GUI.

The Python code for main input data:

```
# Input table with water parameters
WaterSampleTable = gp.GetParameterAsText(4)
# Input feature class of water monitoring stations
WaterSampleStations = gp.GetParameterAsText(5)
# Entering water parameters fields
WaterParameterType4BPK = gp.GetParameterAsText(6)
WaterParameterBPK = gp.GetParameterAsText(7)
WaterParameterMPC4BPK = gp.GetParameterAsText(8)
WaterParameterType4O = gp.GetParameterAsText(9)
WaterParameterO = gp.GetParameterAsText(10)
WaterParameterMPC4O = gp.GetParameterAsText(11)
WaterParameterType4Ph = gp.GetParameterAsText(12)
WaterParameterPh = gp.GetParameterAsText(13)
WaterParameterMPC4Ph = gp.GetParameterAsText(14)
WaterParameter1 = gp.GetParameterAsText(15)
WaterParameterMPC1 = gp.GetParameterAsText(16)
WaterParameter2 = gp.GetParameterAsText(17)
WaterParameterMPC2 = gp.GetParameterAsText(18)
WaterParameter3 = gp.GetParameterAsText(19)
WaterParameterMPC3 = gp.GetParameterAsText(20)
```

The Year and Season parameters confined data for the WQI calculation. The WQI might be calculated for any of four chosen seasons or for a whole year. In the last case the field Season should be left blank. There was a formula for a winter season; the WQI of a winter season was calculated on the basis of January and February of the current year and December of the previous year. The input view for the described parameters is shown in Figure 5-7.

Figure 5-7: The year and season input tool GUI.

The Python code listing for these parameters:

```
Year = gp.GetParameterAsText(21) # query year
PreviousYear = int(Year) - 1 # additional query year for winter query
Season = gp.GetParameterAsText(22) # query season
```

There were two inputs for the shoreline calculation:

- Water level - the value of level of water for a query time period.
- Water pond DEM – the path to the dataset of digital elevation model of water body

And the input for the name of output water quality index raster. The input view for these last three input parameters is shown in Figure 5-8.

Figure 5-8: The shoreline calculation and output raster tool GUI.

The Python code listing for these input parameters:

```
WaterLevel = gp.GetParameterAsText(23) # current level of water for a
water pond
# Digital elevation model of the water pond bottom
DEM = gp.GetParameterAsText(24)
RasterWork = gp.GetParameterAsText(25) # name of output WQI raster
```

It was necessary for the WQI calculation that the all values of the water parameters and/or water pollutants were more than zero. The temporal query table was created for this purpose by the MakeQueryTable geoprocess function.

There were several preprocess steps in Python code for the implementation:

- Generation of list of fields:

```
# List of water parameters
```

```

WaterParameter = WaterParameterBPK + "; " + WaterParameterO + "; " +
WaterParameterPh + "; " + WaterParameterl + "; " + WaterParameter2 + ";
" + WaterParameter3 + "; "
# Common field list for query table
FieldsList = WaterParameter + WaterSampleTableNameField

```

- The season query:

```

# Setting up season part of sql query
if Season == "spring":
    SeasonQuery = " AND (\\"month\\" = 3 OR \\"month\\" = 4 OR \\"month\\" = 5)"
elif Season == "summer":
    SeasonQuery = " AND (\\"month\\" = 6 OR \\"month\\" = 7 OR \\"month\\" = 8)"
elif Season == "autumn":
    SeasonQuery = " AND (\\"month\\" = 9 OR \\"month\\" = 10 OR \\"month\\" = 11)"
elif Season == "winter":
    SeasonQuery = " AND (\\"month\\" = 1 OR \\"month\\" = 2) OR (\\"Year\\" = " +
str(PreviousYear) + " AND \\"month\\" = 12)"
elif Season == "":
    SeasonQuery = ""

```

- The water parameter query:

```

# Setting up water parameter for sql query
WaterParameterQuery = WaterParameterBPK + " > 0 AND " + WaterParameterO
+ " > 0 AND " + WaterParameterPh + " > 0 AND " + WaterParameterl + " >
0 AND " + WaterParameter2 + " > 0 AND " + WaterParameter3 + " > 0 AND "

```

- The whole query:

```

# Whole sql query for a making query table
SQLQuery = WaterParameterQuery + "\"pointkind\" = 'a' AND \\"Year\\" = "
+ str(Year) + SeasonQuery

```

The temporal query table creation:

```

# Make Query Table...
gp.MakeQueryTable(WaterSampleTable,"TempQueryTable","ADD_VIRTUAL_KEY_FI
ELD","",FieldsList,SQLQuery)

```

This part of the code checks absence of results data in the query table:

```

# Checking up for a query result presents
k = 0
QueryRows = gp.searchcursor("TempQueryTable")
QueryRow = QueryRows.next()
while QueryRow:
    k = k + 1
    QueryRow = QueryRows.next()
if k == 0:
    # Exit from workflow in case of absence of query results
    sys.exit("The query with " + Year + ", " + Season + ", " +
WaterParameter + " has no results.")
else:
    QueryRow = QueryRows.reset()

```



```
del QueryRow, QueryRows, k
```

The selected rows potentially give the number of parameter values per water monitoring station. So, it is necessary to average the selected values for the query time period. For this purpose geoprocess Statistic tool and preprocess query were used:

```
# List of water parameters with parameter of calculation - "MEAN" for
each field
WaterParameterMEAN = WaterParameterBPK + " MEAN; " + WaterParameterO +
" MEAN; " + WaterParameterPh + " MEAN; " + WaterParameterl1 + " MEAN; "
+ WaterParameter2 + " MEAN; " + WaterParameter3 + " MEAN; "
# Statistic calculation for chosen water parameters
gp.Statistics("TempQueryTable",uTempStatTable,WaterParameterMEAN,WaterS
ampleTableNameField)
```

The implementation of the WQI formulas was based on CalculateField ArcGIS geoprocessing tool. There were several preprocess steps for this operation: adding field for WQI value to the existed temporal statistic table, preprocessing water parameters, and expression of WQI calculation:

```
# Adding a field in temp statistic table for a wqi calculation
gp.AddField_management(uTempStatTable, "WQI", "FLOAT")
# Translation of string parameters to numeric; checking for MPC values
if WaterParameterType4BPK == 'BOD':
    WaterParameterMPC4BPK = 0
    par10 = 1
else:
    par10 = 2
    if WaterParameterMPC4BPK == "":
        gp.delete(uTempStatTable)
        sys.exit("Please check MPC values!")
if WaterParameterType4O == 'O2':
    WaterParameterMPC4O = 0
    par12 = 1
else:
    par12 = 2
    if WaterParameterMPC4O == "":
        gp.delete(uTempStatTable)
        sys.exit("Please check MPC values!")
if WaterParameterType4Ph == 'pH':
    WaterParameterMPC4Ph = 0
    par14 = 1
else:
    par14 = 2
    if WaterParameterMPC4Ph == "":
        gp.delete(uTempStatTable)
        sys.exit("Please check MPC values!")
# List of water parameters in statistic table with MEAN_ prefix
par1 = str("MEAN_" + WaterParameterBPK.upper())
par2 = str("MEAN_" + WaterParameterO.upper())
par3 = str("MEAN_" + WaterParameterPh.upper())
par4 = str("MEAN_" + WaterParameterl1.upper())
par5 = WaterParameterMPC1
par6 = str("MEAN_" + WaterParameter2.upper())
```

```

par7 = WaterParameterMPC2
par8 = str("MEAN " + WaterParameter3.upper())
par9 = WaterParameterMPC3
par11 = WaterParameterMPC4BPK
par13 = WaterParameterMPC4O
par15 = WaterParameterMPC4Ph
# Expression for field WQI calculation. Names of fields of water
parameters are limited by 16 symbols
ExpressionWQI =
"WQICalculation(%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s)" % ("!" +
par1[0:16]+"!", "!" + par2[0:16]+"!", "!" + par3[0:16]+"!", "!" +
par4[0:16]+"!", par5, "!" + par6[0:16]+"!", par7, "!" + par8[0:16]+"!",
par9, par10, par11, par12, par13, par14, par15)

```

After preprocessing of the necessary variables for the WQI calculation the WQI formula was implemented as Python block inside the CalculateField function:

```

# Codeblock for field calculation. It contains formula for WQI
calculation.
FieldCalcCodeBlock = "def
WQICalculation(WaterParameterBPK,WaterParameterO,WaterParameterPh,Water
Parameter1,WaterParameterMPC1,WaterParameter2,WaterParameterMPC2,WaterP
arameter3,WaterParameterMPC3,WaterParameterType4BPK,WaterParameterMPC4B
PK,WaterParameterType4O,WaterParameterMPC4O,WaterParameterType4Ph,Water
ParameterMPC4Ph):\n\
    if WaterParameterType4BPK == 1:\n\
        if float(WaterParameterBPK) < 3:\n\
            bpk = float(WaterParameterBPK) / 3\n\
        elif float(WaterParameterBPK) <= 15:\n\
            bpk = float(WaterParameterBPK) / 2\n\
        elif float(WaterParameterBPK) > 15:\n\
            bpk = float(WaterParameterBPK) / 1\n\
    else:\n\
        bpk = float(WaterParameterBPK)/float(WaterParameterMPC4BPK)\n\
\n\
    if WaterParameterType4O == 1:\n\
        if float(WaterParameterO) < 1:\n\
            o2 = 60\n\
        elif float(WaterParameterO) < 2:\n\
            o2 = 50\n\
        elif float(WaterParameterO) < 3:\n\
            o2 = 40\n\
        elif float(WaterParameterO) < 4:\n\
            o2 = 30\n\
        elif float(WaterParameterO) < 5:\n\
            o2 = 20\n\
        elif float(WaterParameterO) < 6:\n\
            o2 = 12\n\
        elif float(WaterParameterO) >= 6:\n\
            o2 = 6\n\
    else:\n\
        o2 = float(WaterParameterO)/float(WaterParameterMPC4O)\n\
\n\
    if WaterParameterType4Ph == 1:\n\
        ph = 1\n\

```

```

        if float(WaterParameterPh) < 5 or float(WaterParameterPh) >
9.5:\n\
            ph = 20\n\
        elif float(WaterParameterPh) < 6 or float(WaterParameterPh) >
9:\n\
            ph = 5\n\
        elif float(WaterParameterPh) < 6.5 or float(WaterParameterPh) >
8.5:\n\
            ph = 2\n\
        else:\n\
            ph = float(WaterParameterPh)/float(WaterParameterMPC4Ph)\n\
\n\
        wqi_par =
(bpk+o2+ph+(float(WaterParameter1)/float(WaterParameterMPC1))+(float(Wa
terParameter2)/float(WaterParameterMPC2))+(float(WaterParameter3)/float
(WaterParameterMPC3))) / 6\n\
        return wqi_par"

```

And the coding of CalculateField function:

```

gp.CalculateField_management(uTempStatTable, "WQI", ExpressionWQI,
"PYTHON_9.3", FieldCalcCodeBlock)

```

The next main operation was a Join function, which combined data of the WQI calculation and feature class of water monitoring station disposition. For this purpose the temporal feature layer was made from the feature class of water monitoring station disposition:

```

# Creation of temporal layer from the feature class of monitoring
stations
gp.MakeFeatureLayer(WaterSampleStations, "WaterSampleStationsTemp")
# Join feature class with sample station disposition and table with WQI
calculated
gp.AddJoin_management("WaterSampleStationsTemp",
WaterSampleTableNameField, uTempStatTable,
WaterSampleStationsNameField, "KEEP_COMMON")

```

Before the interpolation the WQI data it was necessary to set up the extent of the study area. In this case this extent depended on shoreline for the water level of the current query. So the shoreline processing was for two purposes: getting the coordinates for the interpolation extent, and preparing the polygon feature for the WQI raster mask. The Python code for these purposes is provided below:

```

# Temp contour feature class of shoreline of water pond based on
current water level
gp.ContourList_sa(DEM, uTempContourList, WaterLevel)
# Converting linear feature class of water shoreline to polygon with a
glance to feature class type: shp or gdb
if WorkspaceType == "FileSystem":
    # Convert Countourlist to polygon
    gp.FeatureToPolygon(uTempContourList + ".shp",
uTempContourListPolygon+ ".shp", "", "NO_ATTRIBUTES")

```

```

gp.Dissolve_management(uTempContourListPolygon + ".shp",
uTempContourListPolygon + "_m" + ".shp", "Id")
gp.delete(uTempContourList + ".shp")
gp.delete(uTempContourListPolygon + ".shp")
else:
    # Convert Countourlist to polygon
    gp.FeatureToPolygon(uTempContourList,
uTempContourListPolygon, "", "NO_ATTRIBUTES")
    gp.Dissolve_management(uTempContourListPolygon,
uTempContourListPolygon + "_m", "Id")
    gp.delete(uTempContourList)
    gp.delete(uTempContourListPolygon)
# Process: Getting Extent
gp.AddMessage ("Getting Extent...")
if WorkspaceType == "FileSystem":
    rows = gp.searchcursor(uTempContourListPolygon + "_m.shp")
else:
    rows = gp.searchcursor(uTempContourListPolygon + "_m")
row = rows.next()
# List of boundary extent values for shoreline feature class
Extent1 = str(row.shape.extent.xmin)
Extent2 = str(row.shape.extent.xmax)
Extent3 = str(row.shape.extent.ymin)
Extent4 = str(row.shape.extent.ymax)
# Ready extent to set up the boundary of extrapolation
Extent = Extent1 + " " + Extent3 + " " + Extent2 + " " + Extent4
row = rows.reset()
del row
del rows
gp.Extent = "%s" % Extent # setting up extent as environmental setting

```

The interpolation of WQI values between water monitoring stations and inside the area of interest (the extent of the shoreline) was based on an inverse distance weighted (IDW) method.

According to Bolstad (2008), the IDW method estimates the value at unknown points using the sampled values and distance to nearby known points. The weight of each sample is an inverse proportion to the distance. The formula for the IDW calculation is:

$$Z_j = \frac{\sum_i \frac{Z_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}} \quad (5.2)$$

Where:

- Z_j is the estimated value for the unknown point at location j
- d_{ij}^n is the distance from known point i to unknown point j
- Z_i is the value for the known point i
- n is a user-defined exponent

The use of this method of interpolation for the current project was proposed and endorsed by the client. Kuyalnik Liman is a shallow water pond without vertical water stratification, and without sharp differences in water parameters values through the liman area. So using of IDW method of interpolation for this project was proper.

Raster, obtained after interpolation, represents the spatial distribution of WQI through the area of interest. Confining the area of the water body by the shoreline the geoprocess tool ExtractByMask was used. The Python code for these functions:

```
# Name of temp WQI raster of whole area of extent
RasterTemp = RasterWork + "t"
# Interpolation of WQI between sample stations and inside Extent
gp.Idw_sa("WaterSampleStationsTemp", string.replace(uTempStatTable,
TempFolder + "/", "") + ":WQI", TempFolder + "/" + RasterTemp, CellSize,
3)
# Clipping WQI raster by feature class of water shoreline with a glance
to feature class type: shp or geodatabase
if WorkspaceType == "FileSystem":
    # Process: ExtractByMask
    gp.ExtractByMask_sa(TempFolder + "/" + RasterTemp,
uTempContourListPolygon + "_m.shp", OutputFolder + "/" + RasterWork)
    gp.delete(uTempContourListPolygon + "_m.shp")
else:
    # Process: ExtractByMask
    gp.ExtractByMask_sa(TempFolder + "/" + RasterTemp,
uTempContourListPolygon + "_m", OutputFolder + "/" + RasterWork)
    gp.delete(uTempContourListPolygon)
```

The symbology import function of the WQI tool is available only in the ArcGIS ArcMap environment. The symbology reference layer was chosen in the tool properties dialog window (Figure 5-9). The Python code for this:

```
# Setting parameter of output WQI raster for ArcGIS ArcMap for layer
symbology import
gp.SetParameter(26, OutputFolder + "/" + RasterWork)
```

Figure 5-9: The WQI tool properties dialog window GUI.

There is an option to save a source table that was used for WQI calculation and interpolation (Figure 5-10). This table gives an ability to check interpolation source data for validity check, reporting, etc. The default value is No.

Figure 5-10: The input view of save a source table parameter.

The Python code for this option:

```
#Saving datatable of sample stations with WQI
TableYesNoParameter = gp.GetParameterAsText(27) #variable to check save
option
OutTableName = RasterWork + "_srctable"
if TableYesNoParameter == "Yes":
    gp.TableToTable_conversion(uTempStatTable, OutputFolder,
OutTableName)
```

Chapter 6 – Results and Analysis

This chapter overviews the project's outcome: the geodatabase design and the toolset issues. The decisions made during project evaluation and possibility of application for different study areas are also analyzed

6.1 The Geodatabase and the Water Quality Index tool

As discussed before, the database structure was offered by the client. This structure required two main functions: to store water sample analysis results and field data and to support easy and fast editing through the ArcGIS ArcMap functions.

Unfortunately, this approach in geodatabase design did not maintain the normalization rules and did not cover whole process of environmental monitoring of the client's study area. It covered only part that support the water quality assessment, including water quality index calculation. It was enough for the current project evaluation. But as soon the client will improve the GIS framework, the geodatabase structure will be changed and it will be necessary to make changes in the toolset coding.

The WQI tool was created in ESRI ArcGIS geoprocessing script environment using Python as a programming language. This approach had both strengths and weaknesses. Also there were several possible ways to implement the WQI formula calculation in ArcGIS environment: ModelBuilder, ArcObject or geoscripting.

ModelBuilder is an ESRI ArcGIS application in which it has been possible to create, edit, and manage step by step processes - models. The ModelBuilder approach usually suits for environmental modeling sphere, but it is still limited in flexibility. And this point was crucial for the project.

ArcObject is a programming interface of ArcGIS applications. It allows to customize ArcGIS or to create an application for a certain purpose. The ArcObject method was most flexible; but for maintaining of the ArcObject product was necessary to have strong programming skill that the client personnel did not have.

Python is OpenSource programming language that integrated into ArcGIS environment. It is free to use and that was really good for the client's small research group with the very limited budget. But absence of professional technical support force developers to spend more time to maintain issues during coding process.

The combination of the Python and geoprocessing allowed to create the WQI tool for ArcGIS environment using geotools from ArcGIS Toolbox well known by the client's personnel. This approach gave clear, understandable, flexible and easy to maintain the WQI toolset. The weakness of this approach was a limitation dedicated to the general functional limitation of the geotools.

6.2 Tool Application

It was mentioned before that the both geodatabase design and the tool structure were customized for the one defined water object – Kuyalnik Liman. And the attempt to implement the results of the current project to any other water object might raise a necessity of the toolset and geodatabase modification.

The Kuyalnik Liman's geodatabase and the WQI toolset had services fields that were mandatory for calculation, but might vary for different water objects. The possibility of change for these parameters embedded in the use and programming environments of ArcGIS, geoprocessing and Python.

The input tabled data of laboratory water samples results (list of measured pollutants with their concentration) had the mandatory service fields for the WQI calculation: "year" for sampling year, "season" for sampling season, "pointkind" for a sample affiliation: to water area of water pond ("a") or to water network ("w"), "n_point" as a name of the water sampling station. The values for "year" and "season" entered by the graphic user interface (Figure 6-1).

Figure 6-1: Year and season input in the WQI toolset GUI

The all mentioned above service fields might be corrected only through the Python code:

```
WaterSampleTableNameField = "n_point" # field name of name of sampling
water analisys results data table
...
WaterSampleStationsNameField = "N_POINT" # field name of name of
sampling station in station feature class
...
Year = gp.GetParameterAsText(21) # query year
...
Season = gp.GetParameterAsText(22) # query season
# Setting up season part of sql query
if Season == "spring":
    SeasonQuery = " AND (\\"month\\" = 3 OR \\"month\\" = 4 OR \\"month\\" =
5)"
elif Season == "summer":
    SeasonQuery = " AND (\\"month\\" = 6 OR \\"month\\" = 7 OR \\"month\\" =
8)"
elif Season == "autumn":
    SeasonQuery = " AND (\\"month\\" = 9 OR \\"month\\" = 10 OR \\"month\\" =
11)"
elif Season == "winter":
    SeasonQuery = " AND (\\"month\\" = 1 OR \\"month\\" = 2) OR (\\"Year\\" =
" + str(PreviousYear) + " AND \\"month\\" = 12)"
elif Season == "":
    SeasonQuery = ""
```


...

```
# Whole sql query for a making query table
```

```
SQLQuery = WaterParameterQuery + "\"pointkind\" = 'a' AND \"Year\" = " + str(Year) + SeasonQuery
```

So the preapplication data processing should consist of two parts: geodatabase preparation in ArcGIS environment and the toolset Python coding correction.

Besides data organization issues there was a challenge related to data processing. The WQI toolset used the inverse distance weighted (IDW) method of interpolation for representation of WQI spatial distribution of Kuyalnik Liman. This method was offered by the client and applied for Kuyalnik Liman. For the implementation of this method to any other water pond, it is necessary to have a foundation for using an IDW interpolation method. For any other interpolation method the toolset Python coding might be changed:

```
# Interpolation of WQI between sample stations and inside Extent
```

```
gp.Idw_sa("WaterSampleStationsTemp", string.replace(uTempStatTable, TempFolder + "/" + "")) + ":WQI", TempFolder + "/" + RasterTemp, CellSize)
```


Chapter 7 – Conclusions and Future Projects

7.1 Conclusions

This project provided the GIS framework (geodatabase and water quality index mapping tool) to support of water quality assessment as a part of environmental monitoring conducted by the client's organization.

The goals were achieved in this project by meeting the following objectives:

- the client received a GIS solution that could support the environmental monitoring process of Kuyalnik Liman in terms of mapping water quality
- the client got a WQI tool that automates manual routine calculation and provides a map in a raster format of a spatial distribution of WQI throughout the liman water area; the shoreline of the obtained raster shows the water level for the research time period of WQI calculation
- the calculation method was applicable to the area of interest and spread in academic and administrative community in Ukraine

For water quality assessment was chosen water quality index (WQI) method. The advantages of this method are: it is a standard approach for water quality assessment, it has meaningful water classification, and its output rating is understandable for non-specialists.

Nature conservation organizations, both administrative and research oriented, use various formulas to calculate WQI. The quality index calculation methodology depends mainly on state affiliation, geographic location of water bodies, type of water use, chemical, and biological factors. Because of its applicability to Kuyalnik Liman and popularity in Ukraine, the method of hydro-chemical index proposed by State Committee of Hydrometeorology of the USSR (1986) was chosen as the theoretical base for this project. Currently it is the commonly used method of WQI determination in Ukraine. It represents an average fraction of limits exceeding six parameters. These might be water parameters: such biological oxygen demand, dissolved oxygen, pH and/or water pollutants that are specific for study area.

The ESRI software was a standard GIS framework for the client, so the WQI mapping tool was intended to use in ArcGIS environment as a Toolbox toolset. ESRI geodatabase was used as storage for input data. Python language was used as a programming environment. It is opensource language and that is very good because of limited budget of client's research organizations.

Water monitoring stations, bathymetry data of Kuyalnik Liman and water attributes are stored in ESRI File geodatabase. This database format was chosen as scalable and speedy choice for a small group of the client's users and because this kind of geodatabase allows storing rasters and has improved editing model. The input for the WQI tool was preprocessed from rough data. The water monitoring stations layer was represented by point feature class and it located the disposition of 18 water sampling stations through the liman area. This data was collected using handheld GARMIN GPS devices during field work. The bathymetry data of Kuyalnik Liman was based on a field survey that was conducted by Ukrainian Research Institution of Balneology in 1975. The four paper maps from the report represented the network of depth measurements of Kuyalnik Liman. The

maps contained the point data with elevation marked in Baltic Elevation System and three isolines of depth in BES of Kuyalnik Liman. These maps were scanned, projected at WGS 1984 UTM Zone 36N projection and digitized. From the obtained vector data mentioned bathymetry raster of Kuyalnik Liman was created.

There were three main blocks in tool workflow: water quality index calculation, interpolation through the study area, and a creation of outline of Kuyalnik Liman. Water quality index calculation was an implementation of the mentioned WQI formula with Python language. The formula used values of six pollutants or water parameters and their maximum permissible concentrations. The interpolation block provided spatial interpolation through the study area. For this the inverse distance weighted (IDW) method was used. The third block was responsible to outline the current water level of spatial distribution of water quality index raster on basis of bathymetry data. Also there was a possibility to inherit a classification symbology from a reference layer. This function worked only for ArcMap environment. The water quality index toolset was represented by regular ArcGIS GUI form for geoprocessing tools. The result data was a spatial distribution of water quality index through Kuyalnik Liman in ArcGIS raster format.

7.2 Future projects

The WQI tool was created as a GIS support for water quality assessment of Kuyalnik Liman as an analysis basement for administrative and natural management decision making support. There are few related topics that might be used for future projects: web resource of water quality or GIS framework for environment monitoring with set of water quality tools.

7.2.1 Web resource

The web resource should provide to user current situation of environmental condition of water of Kuyalnik Liman or any other water body.

The mapping resource should be based on map of hydro-chemical index of water quality (WQI) and maps of separate water pollutants. The calculation of WQI might be based on the method proposed by State Committee of Hydrometeorology of the USSR (1986) or any other methodologies of water quality index calculation. The example of simple water quality web resource for Kuyalnik Liman is shown at Figure 7-1.

Figure 7-1: The example of water quality web resource for Kuyalnik Liman.

The minimal functionality of the web resource:

- operation functions: zoom in/out, zoom to selected area, table of content with ability switching layers on/off
- query functions: temporal querying by year and/or seasons, querying by pollutants or water quality indices, spatial querying by water monitoring stations
- mapping function: map creation on the basis of query, output map print
- report function: report creation on the basis of query, report print

The web resource might serve as a resource of up-to-date information of environmental condition of Kuyalnik Liman.

7.2.2 GIS framework for water quality assessment with set of water quality tools

The proposed project should include geodatabase design with using of normalization rules and set of tools for water quality assessment. These tools might be based on both hydro-chemical and hydro-biological parameters. For example, Shitiokov et al. (2003) proposed several methods of WQI calculation:

Based only on hydro-chemical variables:

- Parameter of chemical water pollution, calculated on the basis exceeding limits of 10 water parameters
- Combinatorial index of pollution, based on limits exceeding, multiplicity and its frequency

- Method from the Science Research Institution for Hygiene of F.F. Erisman, that takes into account exceeding levels of chemical, microbe, and organoleptic parameters

And classification on the basis of hydro-biological parameters:

- System of water quality classification by Bylinkina A.A. and Drachev S. M.

This GIS framework should cover the whole process of environmental monitoring of the client's study area to support all steps of water quality assessment.

Works Cited

- Bolstad, P. (2008). GIS Fundamentals. A First Text on Geographic Information Systems. Third Edition. White Bear Lake, MN: Eider Press.
- Cabinet of Ministry of Ukraine (1996). Enactment № 1499 from December 11, 1996. Approving of the list of water bodies classified as medical. Kiev: Cabinet of Ministry of Ukraine
- Canadian Council of Ministers of the Environment (2001). Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, Technical Report. Winnipeg: Canadian Council of Ministers of the Environment
- Childs, C. (2009). The Top Nine Reasons to Use a File Geodatabase. *Arc User*. Spring 2009. Retrieved May 28, 2010, from <http://www.esri.com/news/arcuser/0309/files/9reasons.pdf>
- Cude, C. G. (2001). Oregon Water Quality Index: A tool for Evaluating Water Quality Management Effectiveness. *Journal of the American Water Resources Association*, 37(1), 125-137.
- ESRI (2010). ArcGIS Desktop 9.3 Help: Topo to Raster. May 31, 2010, http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=6277&pid=6268&topicname=Topo_to_Raster
- Hambright, K. D., Parparov, A. & Berman, T. (2000). Indices of water quality for sustainable management and conservation of an arid region lake, Lake Kinneret (Sea of Galilee), Israel. *Aquatic Conservation: Marine and Freshwater Ecosystems*, (10), 393–406.
- Kurakina, N. I., Emelyanova V. N., Korobeynikov S. A. & Nikanorova E. S. (2006). Spatial modeling of pollution of water objects. *ArcReview*, (36), 4-7.
- Maidment, D. R. (2002). Arc Hydro. GIS for Water Resources. Redlands, CA: ESRI Press.
- Shitiokov V. K., Rozenberg G. S. & Zinchenko T. D. (2003). *Quantitative hydroecology: methods of system identification*. October 4, 2009, <http://www.ievbran.ru/Kiril/Library/Book1/content0/content0.htm#Ref>
- Srinivasan, R., Arnold, J. G. (1993). Basin scale water quality modeling using GIS. *Application of Advanced Information Technologies: Effective Management of Natural Resources*, 475-484.
- State Committee of Hydrometeorology of USSR (1986). Temporary methodological instructions of complex estimation of quality of surface and sea water. Approved by State Committee of Hydrometeorology of USSR 22.09.1986 №250-1163. M: State Committee of Hydrometeorology.
- Stoner, J. D. (1978) Water-Quality Indices for Specific Water Uses. Geological Survey circular 770. VA: US Geological Survey.
- Timchenko V.M. (1990) Ecohydrological research of North-West Black Sea Littoral Limans. – Kiev: Naukova Dumka.
- UkrRIbalneology (1975). The detailed exploration and calculation of reserve of silt mud of Kuyalnik Liman. The report of UkrRIbalneology (1975). Odessa: Archive of UkrRIbalneology.
- United States Environmental Protection Agency (2009). October 4, 2009, <http://www.epa.gov/waterscience/models/>.

- Wright, D. J., Blongewicz, M.J., Halpin, P. N. & Breman, J. (2007). Arc Marine. GIS for a Blue Planet. Redlands, CA: ESRI Press.
- Zhang, Bo (2008). A study of GIS-SD based temporal-spatial modeling of water quality in water pollution accidents. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, (XXXVII. Part B2), 155-160.

Appendix A. The tables of the geodatabase structure classes

Table A-1. Table of water samples parameters.

Alias	Water samples parameters				
Dataset Type	Table				
Field Name	Alias Name	Type	Length	Null	
OBJECTID	OBJECTID	OID	4	No	
month	Month	Small Integer	2	Yes	
season	Season	String	10	Yes	
year	Year	Small Integer	2	Yes	
pointkind	Type of sample	String	1	Yes	
susp_substance	Suspended substances, g/l	Single	4	Yes	
transparency	Transparency, cm	Single	4	Yes	
color	Color, grad	Single	4	Yes	
pH	pH	Single	4	Yes	
chlorides	Chlorides, mg/l	Single	4	Yes	
sulphates	Sulphates, mg/l	Single	4	Yes	
sulphides	Sulphides, mg/l	Single	4	Yes	
hydr_carbonates	Hydrocarbonates, mg-ekv/l	Single	4	Yes	
Na	Na, mg/l	Single	4	Yes	
K	K, mg/l	Single	4	Yes	
Ca	Ca, mg/l	Single	4	Yes	
Mg	Mg, mg/l	Single	4	Yes	
hardness	Hardness, mg-ekv/l	Single	4	Yes	
solid_res	Solid residue, g/l	Single	4	Yes	
salinity	Salinity, promille	Single	4	Yes	
chem_oxygen_demand	Chemical oxygen demand, mg/l	Single	4	Yes	
biochem_oxygen_demand	Biochemical oxygen demand, mg/l	Single	4	Yes	
dissolved_oxygen	Dissolved oxygen, mg/l	Single	4	Yes	
nitrate	Nitrates, mg/l	Single	4	Yes	
nitrite	Nitrites, mg/l	Single	4	Yes	
N_ammonium	N ammonium, mg/l	Single	4	Yes	
phosphates	Phosphates, mg/l	Single	4	Yes	
SiO2	SiO2, g/l	Single	4	Yes	
phenol	Phenols, mg/l	Single	4	Yes	
formaldehyde	Formaldehyde, mg/l	Single	4	Yes	
oil_chloroform	Oil products (chl), mg/l	Single	4	Yes	
oil_hexan	Oil products (hex), mg/l	Single	4	Yes	
Al	Al, mg/l	Single	4	Yes	
Mn	Mn, mg/l	Single	4	Yes	
Cu	Cu, mg/l	Single	4	Yes	
Pb	Pb, mg/l	Single	4	Yes	
Cd	Cd, mg/l	Single	4	Yes	
Cr	Cr, mg/l	Single	4	Yes	
V	V, mg/l	Single	4	Yes	
Fe	Fe, mg/l	Single	4	Yes	
Zn	Zn	Single	4	Yes	
N_min	N mineral, mg/l	Single	4	Yes	
oxygenation	Oxygenation, %	Single	4	Yes	

Oil_mikran	Oil products (mikran), mg/l	Single	4	Yes
day	Day	Small Integer	2	Yes
fluorides	Fluorides, mg/l	Single	4	Yes
borate	Borate, mg/l	Single	4	Yes
bromide	Bromide, mg/l	Single	4	Yes
chlorophyll	Chlorophyll “a”, mkg/l	Single	4	Yes
salt_content	Salt content, g/l	Single	4	Yes
sampl_date	Date of water sampling	Date	8	Yes
w_temp	Water temperature, C	Small Integer	2	Yes
n_point	Name	String	50	Yes
Domains				
month				
season				
pointkind				

Table A-2. Table of maximum permissible concentrations.

Alias	Maximum permissible concentration for water resource				
Dataset Type	Table				
Field Name	Alias Name	Type	Length	Null	
OBJECTID	OBJECTID	OID	4	No	
susp_substance	Suspended substances, g/l	Single	4	Yes	
transparency	Transparency, cm	Single	4	Yes	
color	Color, grad	Single	4	Yes	
pH	pH	Single	4	Yes	
chlorides	Chlorides, mg/l	Single	4	Yes	
sulphates	Sulphates, mg/l	Single	4	Yes	
sulphides	Sulphides, mg/l	Single	4	Yes	
hydr_carbonates	Hydrocarbonates, mg-ekv/l	Single	4	Yes	
Na	Na, mg/l	Single	4	Yes	
K	K, mg/l	Single	4	Yes	
Ca	Ca, mg/l	Single	4	Yes	
Mg	Mg, mg/l	Single	4	Yes	
hardness	Hardness, mg-ekv/l	Single	4	Yes	
solid_res	Solid residue, g/l	Single	4	Yes	
salinity	Salinity, promille	Single	4	Yes	
chem_oxygen_demand	Chemical oxygen demand, mg/l	Single	4	Yes	
biochem_oxygen_demand	Biochemical oxygen demand, mg/l	Single	4	Yes	
dissolved_oxygen	Dissolved oxygen, mg/l	Single	4	Yes	
nitrate	Nitrates, mg/l	Single	4	Yes	
nitrite	Nitrites, mg/l	Single	4	Yes	
N_ammonium	N ammonium, mg/l	Single	4	Yes	
phosphates	Phosphates, mg/l	Single	4	Yes	
SiO2	SiO2, g/l	Single	4	Yes	
phenol	Phenols, mg/l	Single	4	Yes	
formaldehyde	Formaldehyde, mg/l	Single	4	Yes	
oil_chloroform	Oil products (chl), mg/l	Single	4	Yes	
oil_hexan	Oil products (hex), mg/l	Single	4	Yes	
Al	Al, mg/l	Single	4	Yes	
Mn	Mn, mg/l	Single	4	Yes	
Cu	Cu, mg/l	Single	4	Yes	
Pb	Pb, mg/l	Single	4	Yes	
Cd	Cd, mg/l	Single	4	Yes	
Cr	Cr, mg/l	Single	4	Yes	

V	V, mg/l	Single	4	Yes
Fe	Fe, mg/l	Single	4	Yes
Zn	Zn	Single	4	Yes
N_min	N mineral, , mg/l	Single	4	Yes
oxygenation	Oxygenation, %	Single	4	Yes
Oil_mikran	Oil products (mikran), mg/l	Single	4	Yes
fluorides	Fluorides, , mg/l	Single	4	Yes
borate	Borate, mg/l	Single	4	Yes
bromide	Bromide, mg/l	Single	4	Yes
chlorophyll	Chlorophyll “a”, mkg/l	Single	4	Yes
salt_content	Salt content, g/l	Single	4	Yes
type_wat_use	Type of water use	String	10	Yes
iss_agency	Issued agency	String	10	Yes
Domains				
type_wat_use				
iss_agency				

Table A-3. Feature class of water monitoring stations.

Alias	Water monitoring stations				
Dataset Type	FeatureClass				
Geometry:	Point				
Field Name	Alias Name	Type	Length	Null	
OBJECTID	OBJECTID	OID	4	No	
SHAPE	SHAPE	Geometry0		Yes	
point	Old name	String	50	No	
pointkind	Type of sample	String	1	No	
Zone	Zone	String	50	No	
n_point	Name	String	50	Yes	
Domains					
pointkind					
zone					

Table A-4. Geodatabase domains.

iss_agency	
Description	The water standards issued agency
Domain Type	Coded Value
Field Type	String
Domain Members	
Name	Value
EU	eu
WHO	who
Ministry of health of Ukraine	ua
month	
Description	Month
Domain Type	Coded Value
Field Type	Small Integer
Domain Members	
Name	Value
January	1
February	2
March	3

April	4
May	5
June	6
July	7
August	8
September	9
October	10
November	11
December	12
<i>pointkind</i>	
Description	The water monitoring station affiliation
Domain Type	Coded Value
Field Type	String
Domain Members	
Name	Value
water area	a
water network	w
<i>season</i>	
Description	Season
Domain Type	Coded Value
Field Type	String
Domain Members	
Name	Value
Spring	spring
Summer	summer
Autumn	autumn
Winter	winter
<i>type_wat_use</i>	
Description	The type of water use
Domain Type	Coded Value
Field Type	String
Domain Members	
Name	Value
Drinking water	drnk
Recreational water	recr
<i>zone</i>	
Description	The water pond zones
Domain Type	Coded Value
Field Type	String
Domain Members	
Name	Value
North	north
Center	center
South	south
Water network	water network

Table A-5. Relationship class.

<i>Points2Water</i>	
Composite	No
Cardinality	One To Many
Notification	None
Attributed	No
Origin	Destination

ObjectClass	water_sample_station_disposition		water_sample_results	
Key	n_point (<i>Origin Primary Key</i>)		n_point (<i>Origin Foreign Key</i>)	
Labels	points		water	
Rules	Subtype	Origin Cardinality	Subtype	Destination Cardinality
	water_sample_station_disposition		water_sample_results	
				M

Table A-6. The specification of the water pond elevation class.

DEM	
Columns and Rows	1248, 1248
Number of Bands	1
Cell size	10, 10
Source type	continuous
Pixel type	floating point
Pixel Depth	32 bit

Appendix B. The listing of the WQI tool Python code

```
# Import scripting modules
import arcgisscripting, string, sys

# Create geoprocess object
gp = arcgisscripting.create(9.3)

# Permit to overwright data
gp.OverWriteOutput = 1

# Setup temp and scratch folders
TempFolder = gp.GetParameterAsText(0)
gp.ScratchWorkspace = TempFolder

CoordSystem = gp.GetParameterAsText(1) # entering coordinate system
from ArcGIS GUI

gp.CartographicCoordinateSystem = CoordSystem

CellSize = str(gp.GetParameterAsText(2)) # cell size for output raster

OutputFolder = gp.GetParameterAsText(3)

WaterSampleTable = gp.GetParameterAsText(4) # input table with water
parameters

WaterSampleTableNameField = "n_point" # field name of name of sampling
station water analisys results data table

WaterSampleStations = gp.GetParameterAsText(5) # input feature class of
water monitoring stations

WaterSampleStationsNameField = "N_POINT" # field name of name of
sampling station in station feature class

# Entering water parameters fields

WaterParameterType4BPK = gp.GetParameterAsText(6)
WaterParameterBPK = gp.GetParameterAsText(7)
WaterParameterMPC4BPK = gp.GetParameterAsText(8)
WaterParameterType4O = gp.GetParameterAsText(9)
WaterParameterO = gp.GetParameterAsText(10)
WaterParameterMPC4O = gp.GetParameterAsText(11)
WaterParameterType4Ph = gp.GetParameterAsText(12)
WaterParameterPh = gp.GetParameterAsText(13)
WaterParameterMPC4Ph = gp.GetParameterAsText(14)
WaterParameterI1 = gp.GetParameterAsText(15)
WaterParameterMPC1 = gp.GetParameterAsText(16)
WaterParameter2 = gp.GetParameterAsText(17)
WaterParameterMPC2 = gp.GetParameterAsText(18)
```

```

WaterParameter3 = gp.GetParameterAsText(19)
WaterParameterMPC3 = gp.GetParameterAsText(20)
# List of water parameters
WaterParameter = WaterParameterBPK + "; " + WaterParameterO + "; " +
WaterParameterPh + "; " + WaterParameter1 + "; " + WaterParameter2 + ";
" + WaterParameter3 + "; "
# Common field list for making query table
FieldsList = WaterParameter + WaterSampleTableNameField
Year = gp.GetParameterAsText(21) # query year
PreviousYear = int(Year) - 1 # additional query year for winter query
Season = gp.GetParameterAsText(22) # query season
# Setting up season part of sql query
if Season == "spring":
    SeasonQuery = " AND (\\"month\\" = 3 OR \\"month\\" = 4 OR \\"month\\" =
5)"
elif Season == "summer":
    SeasonQuery = " AND (\\"month\\" = 6 OR \\"month\\" = 7 OR \\"month\\" =
8)"
elif Season == "autumn":
    SeasonQuery = " AND (\\"month\\" = 9 OR \\"month\\" = 10 OR \\"month\\" =
11)"
elif Season == "winter":
    SeasonQuery = " AND (\\"month\\" = 1 OR \\"month\\" = 2) OR (\\"Year\\" =
" + str(PreviousYear) + " AND \\"month\\" = 12)"
elif Season == "":
    SeasonQuery = ""
# Setting up water parameter for sql query
WaterParameterQuery = WaterParameterBPK + " > 0 AND " + WaterParameterO
+ " > 0 AND " + WaterParameterPh + " > 0 AND " + WaterParameter1 + " >
0 AND " + WaterParameter2 + " > 0 AND " + WaterParameter3 + " > 0 AND "
# Whole sql query for a making query table
SQLQuery = WaterParameterQuery + "\"pointkind\\" = 'a' AND \\"Year\\" = "
+ str(Year) + SeasonQuery
WaterLevel = gp.GetParameterAsText(23) # current level of water for a
water pond
DEM = gp.GetParameterAsText(24) # digital elevation model of the water
pond bottom
# Cheking for workspace type
WorkspaceType = gp.describe(TempFolder).WorkspaceType
# Make Query Table...
gp.AddMessage ("Making Query Table...")

```

```

gp.MakeQueryTable(WaterSampleTable,"TempQueryTable","ADD_VIRTUAL_KEY_FIEL
ELD","",FieldsList,SQLQuery)

# Checking up for a query result presents
k = 0

QueryRows = gp.searchcursor("TempQueryTable")
QueryRow = QueryRows.next()
while QueryRow:
    k = k + 1
    QueryRow = QueryRows.next()
if k == 0:
    sys.exit("The query with " + Year + ", " + Season + ", " +
WaterParameter + " has no results.") # exit from workflow in case of
absence of query results
else:
    QueryRow = QueryRows.reset()
    del QueryRow, QueryRows, k
gp.AddMessage ("Query Table - Done")

# Summary statistic
gp.AddMessage ("Starting Summary statistic...")
# Setting up unique name for a statistic temp table
uTempStatTable = gp.createuniqueName(TempFolder + "/" +
"TempStatTable")

# List of water parameters with parameter of calculation - "MEAN" for
each field
WaterParameterMEAN = WaterParameterBPK + " MEAN; " + WaterParameterO +
" MEAN; " + WaterParameterPh + " MEAN; " + WaterParameterl + " MEAN; "
+ WaterParameter2 + " MEAN; " + WaterParameter3 + " MEAN; "

# Statistic calculation for chosen water parameters
gp.Statistics("TempQueryTable",uTempStatTable,WaterParameterMEAN,WaterS
ampleTableNameField)
gp.AddMessage ("Summary statistic - Done")

# Creation of temporal layer from the feature class of monitoring
stations
gp.AddMessage ("Making a layer from the feature class...")
gp.MakeFeatureLayer(WaterSampleStations,"WaterSampleStationsTemp")
gp.AddMessage ("Making a layer from the feature class - Done")

# WQI calculation
# Adding a field in temp statistic table for a WQI calculation
gp.AddField_management(uTempStatTable, "WQI", "FLOAT")
# Translation of string parameters to numeric; checking for MPC values

```



```

if WaterParameterType4BPK == 'BOD':
    WaterParameterMPC4BPK = 0
    par10 = 1
else:
    par10 = 2
    if WaterParameterMPC4BPK == "":
        gp.delete(uTempStatTable)
        sys.exit("Please check MPC values!")
if WaterParameterType4O == 'O2':
    WaterParameterMPC4O = 0
    par12 = 1
else:
    par12 = 2
    if WaterParameterMPC4O == "":
        gp.delete(uTempStatTable)
        sys.exit("Please check MPC values!")
if WaterParameterType4Ph == 'pH':
    WaterParameterMPC4Ph = 0
    par14 = 1
else:
    par14 = 2
    if WaterParameterMPC4Ph == "":
        gp.delete(uTempStatTable)
        sys.exit("Please check MPC values!")

# List of water parameters in statistic table with MEAN_ prefix
par1 = str("MEAN_" + WaterParameterBPK.upper())
par2 = str("MEAN_" + WaterParameterO.upper())
par3 = str("MEAN_" + WaterParameterPh.upper())
par4 = str("MEAN_" + WaterParameter1.upper())
par5 = WaterParameterMPC1
par6 = str("MEAN_" + WaterParameter2.upper())
par7 = WaterParameterMPC2
par8 = str("MEAN_" + WaterParameter3.upper())
par9 = WaterParameterMPC3
par11 = WaterParameterMPC4BPK
par13 = WaterParameterMPC4O
par15 = WaterParameterMPC4Ph

```

```
# Expression for field WQI calculation. Water parameters are limited by
16 symbols
```

```
ExpressionWQI =
"WQICalculation(%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s,%s)" % ("!" +
par1[0:16]+"!", "!" + par2[0:16]+"!", "!" + par3[0:16]+"!", "!" +
par4[0:16]+"!", par5, "!" + par6[0:16]+"!", par7, "!" + par8[0:16]+"!",
par9, par10, par11, par12, par13, par14, par15)
```

```
# Codeblock for field calculation. It contains formula for WQI
calculation.
```

```
FieldCalcCodeBlock = "def
WQICalculation(WaterParameterBPK,WaterParameterO,WaterParameterPh,Water
Parameter1,WaterParameterMPC1,WaterParameter2,WaterParameterMPC2,WaterP
arameter3,WaterParameterMPC3,WaterParameterType4BPK,WaterParameterMPC4B
PK,WaterParameterType4O,WaterParameterMPC4O,WaterParameterType4Ph,Water
ParameterMPC4Ph):\n\
```

```
    if WaterParameterType4BPK == 1:\n\
        if float(WaterParameterBPK) < 3:\n\
            bpk = float(WaterParameterBPK) / 3\n\
        elif float(WaterParameterBPK) <= 15:\n\
            bpk = float(WaterParameterBPK) / 2\n\
        elif float(WaterParameterBPK) > 15:\n\
            bpk = float(WaterParameterBPK) / 1\n\
    else:\n\
        bpk = float(WaterParameterBPK)/float(WaterParameterMPC4BPK)\n\
```

```
\n\
```

```
    if WaterParameterType4O == 1:\n\
        if float(WaterParameterO) < 1:\n\
            o2 = 60\n\
        elif float(WaterParameterO) < 2:\n\
            o2 = 50\n\
        elif float(WaterParameterO) < 3:\n\
            o2 = 40\n\
        elif float(WaterParameterO) < 4:\n\
            o2 = 30\n\
        elif float(WaterParameterO) < 5:\n\
            o2 = 20\n\
        elif float(WaterParameterO) < 6:\n\
            o2 = 12\n\
        elif float(WaterParameterO) >= 6:\n\
            o2 = 6\n\
    else:\n\
```

```

        o2 = float(WaterParameterO)/float(WaterParameterMPC4O)\n\
\n\
        if WaterParameterType4Ph == 1:\n\
            ph = 1\n\
            if float(WaterParameterPh) < 5 or float(WaterParameterPh) >
9.5:\n\
                ph = 20\n\
            elif float(WaterParameterPh) < 6 or float(WaterParameterPh) >
9:\n\
                ph = 5\n\
            elif float(WaterParameterPh) < 6.5 or float(WaterParameterPh) >
8.5:\n\
                ph = 2\n\
        else:\n\
            ph = float(WaterParameterPh)/float(WaterParameterMPC4Ph)\n\
\n\
        wqi_par =
(bpk+o2+ph+(float(WaterParameter1)/float(WaterParameterMPC1))+(float(Wa
terParameter2)/float(WaterParameterMPC2))+(float(WaterParameter3)/float
(WaterParameterMPC3))) / 6\n\
        return wqi_par"

gp.CalculateField_management(uTempStatTable, "WQI", ExpressionWQI,
"PYTHON_9.3", FieldCalcCodeBlock)

# Process: Add Join...
gp.AddMessage ("Process: Add Join...")

# Join feature class with sample station disposition and table with WQI
calculated

gp.AddJoin_management("WaterSampleStationsTemp",
WaterSampleTableNameField, uTempStatTable,
WaterSampleStationsNameField, "KEEP_COMMON")

gp.AddMessage ("Process: Add Join - Done")

# Check out ArcGIS Spatial Analyst extension license
gp.CheckOutExtension("Spatial")

# Process: ContourList
gp.AddMessage ("Process: ContourList...")

# Setting up unique name for a temp linear contour feature class
uTempContourList = gp.createuniqueName(TempFolder + "/" +
"TempContourList")

# Temp contour feature class of shoreline of water pond based on
current water level
gp.ContourList_sa(DEM, uTempContourList, WaterLevel)

```

```

gp.AddMessage ("Process: ContourList - Done")
gp.AddMessage ("Converting Countourlist to polygon...")
# Setting up unique name for a temp polygon contour feature class
uTempContourListPolygon = gp.createuniquename(TempFolder + "/" +
"TempContourListPolygon")
# Converting linear feature class of water shoreline to polygon with a
glance to feature class type: shp or gdb
if WorkspaceType == "FileSystem":
    # Convert Countourlist to polygon
    gp.FeatureToPolygon(uTempContourList + ".shp",
uTempContourListPolygon+ ".shp", "", "NO_ATTRIBUTES")
    gp.Dissolve_management(uTempContourListPolygon + ".shp",
uTempContourListPolygon + "_m" + ".shp", "Id")
    gp.delete(uTempContourList + ".shp")
    gp.delete(uTempContourListPolygon + ".shp")
else:
    # Convert Countourlist to polygon
    gp.FeatureToPolygon(uTempContourList,
uTempContourListPolygon, "", "NO_ATTRIBUTES")
    gp.Dissolve_management(uTempContourListPolygon,
uTempContourListPolygon + "_m", "Id")
    gp.delete(uTempContourList)
    gp.delete(uTempContourListPolygon)
gp.AddMessage ("Converting Countourlist to polygon - Done")
# Check out ArcGIS Spatial Analyst extension license
gp.CheckOutExtension("Spatial")
# Process: Getting Extent
gp.AddMessage ("Getting Extent...")
if WorkspaceType == "FileSystem":
    rows = gp.searchcursor(uTempContourListPolygon + "_m.shp")

else:
    rows = gp.searchcursor(uTempContourListPolygon + "_m")
row = rows.next()
# List of boundary extent values for shoreline feature class
Extent1 = str(row.shape.extent.xmin)
Extent2 = str(row.shape.extent.xmax)
Extent3 = str(row.shape.extent.ymin)
Extent4 = str(row.shape.extent.ymax)

```

```

# Ready extent to set up the boundary of extrapolation
Extent = Extent1 + " " + Extent3 + " " + Extent2 + " " + Extent4
row = rows.reset()
del row
del rows

gp.AddMessage ("Getting Extent - Done")
gp.Extent = "%s" % Extent # setting up extent as environmental setting
gp.AddMessage ("Process: Interpolation: Extent - Done")
# Process: Interpolation
gp.AddMessage ("Process: Interpolation...")
RasterWork = gp.GetParameterAsText(25) # name of output WQI raster
RasterTemp = RasterWork + "t" # name of temp WQI raster of whole area
of extent
# Interpolation of WQI between sample stations and inside Extent
gp.Idw_sa("WaterSampleStationsTemp", string.replace(uTempStatTable,
TempFolder + "/" , "") + ":WQI", TempFolder + "/" + RasterTemp, CellSize,
3)
gp.AddMessage ("Process: Interpolation - Done")
# Check out ArcGIS Spatial Analyst extension license
gp.CheckOutExtension("Spatial")
gp.AddMessage ("Process: ExtractByMask...")
# Clipping WQI raster by feature class of water shoreline with a glance
to feature class type: shp or geodatabase
if WorkspaceType == "FileSystem":
    # Process: ExtractByMask
    gp.ExtractByMask_sa(TempFolder + "/" + RasterTemp,
uTempContourListPolygon + "_m.shp", OutputFolder + "/" + RasterWork)
    gp.delete(uTempContourListPolygon + "_m.shp")
else:
    # Process: ExtractByMask
    gp.ExtractByMask_sa(TempFolder + "/" + RasterTemp,
uTempContourListPolygon + "_m", OutputFolder + "/" + RasterWork)
    gp.delete(uTempContourListPolygon)
# Setting parameter of output WQI raster for ArcGIS ArcMap for layer
symbology import
gp.SetParameter(26, OutputFolder + "/" + RasterWork)
gp.AddMessage ("Process: ExtractByMask - Done")
#Saving datatable of sample stations with WQI
TableYesNoParameter = gp.GetParameterAsText(27) #variable to check save
option

```

```
OutTableName = RasterWork + "_srctable"
if TableYesNoParameter == "Yes":
    gp.TableToTable_conversion(uTempStatTable, OutputFolder,
OutTableName)
#Free memory & space
gp.delete(TempFolder + "/" + RasterTemp)
gp.delete(uTempStatTable)
gp.AddMessage ("All done!")
del gp
```

Appendix C. The copy of WQI methodology in original (Russian) language

Гидрохимический индекс загрязнения воды (ИЗВ) установлен Госкомгидрометом СССР и относится к категории показателей, наиболее часто используемых для оценки качества водных объектов. Этот индекс является типичным аддитивным коэффициентом и представляет собой среднюю долю превышения ПДК по строго лимитированному числу индивидуальных ингредиентов:

$$\text{ИЗВ} = \frac{1}{n} * \sum_{i=1}^n \frac{C_i}{\text{ПДК}_i}$$

где:

- C_i – концентрация компонента (в ряде случаев – значение физико-химического параметра);
- n – число показателей, используемых для расчета индекса, $n = 6$;
- ПДК_i – установленная величина норматива для соответствующего типа водного объекта.

Для расчета индекса загрязнения вод для всего множества нормируемых компонентов, включая водородный показатель pH, биологическое потребление кислорода БПК₅ и содержание растворенного кислорода, находят отношения $C_i/\text{ПДК}_i$ фактических концентраций к ПДК и полученный список сортируют. ИЗВ рассчитывают строго по шести показателям, имеющим наибольшие значения приведенных концентраций, независимо от того превышают они ПДК или нет.

При расчете ИЗВ для составляющих $C_i/\text{ПДК}_i$ по неоднозначно нормируемым компонентам применяется ряд следующих условий:

- для биологического потребления кислорода БПК₅ (ПДК – не более 3 мг О₂/дм³ для водоемов хозяйственно-питьевого водопользования и не более 6 мг О₂/дм³ для водоемов хозяйственно-бытового и культурного водопользования) устанавливаются специальные значения нормативов, зависящие от самого значения БПК₅:

<u>Показатель БПК₅ (мгО₂/л)</u>	<u>Значение норматива (ПДК)</u>
Менее 3	3
От 3 до 15	2
Свыше 15	1

- концентрация растворенного кислорода нормируется с точностью до наоборот: его содержание в пробе не должно быть ниже 4 мг/дм³, поэтому для каждого диапазона концентраций компонента устанавливаются специальные значения слагаемых $C_i/\text{ПДК}_i$:

<u>Концентрация (мгО₂/л)</u>	<u>Значение слагаемого $C_i/\text{ПДК}_i$</u>
Более или равно 6	6

Менее 6 до 5	12
Менее 5 до 4	20
Менее 4 до 3	30
Менее 3 до 2	40
Менее 2 до 1	50
Менее 1	60

- для водородного показателя pH действующие нормативы для воды водоемов различного назначения регламентируют диапазон допустимых значений в интервале от 6,5 до 8,5, поэтому для каждого сверхнормативного значения pH, выходящего за границы этого диапазона, устанавливаются специальные значения слагаемых $C_i / ПДК_i$:

<u>Значения pH ниже</u> <u>диапазона нормы (< 6.5)</u>	<u>Значения pH выше</u> <u>диапазона нормы (> 8.5)</u>	<u>Значение слагаемого</u> <u>$C_i / ПДК_i$</u>
Менее 6.5 до 6	Свыше 8.5 до 9	2
Менее 6 до 5	Свыше 9 до 9.5	5
Менее 5	Свыше 9.5	20

В зависимости от величины ИЗВ участки водных объектов подразделяют на классы. Устанавливается требование, чтобы индексы загрязнения воды сравнивались для водных объектов одной биогеохимической провинции и сходного типа, для одного и того же водотока (по течению, во времени, и так далее), а также с учетом фактической водности текущего года.

Классы качества вод в зависимости от значения индекса загрязнения воды:

<u>Воды</u>	<u>Значения ИЗВ</u>	<u>Классы качества вод</u>
Очень чистые	до 0,2	I
Чистые	0,2–1,0	II
Умеренно загрязненные	1,0–2,0	III
Загрязненные	2,0–4,0	IV
Грязные	4,0–6,0	V
Очень грязные	6,0–10,0	VI
Чрезвычайно грязные	>10,0	VII