



**UNIVERSITÉ
DE GENÈVE**

Geographic Information Systems (GIS) based investigations of hydrocarbon pollution in the region of Ogoniland, Nigeria

-

Promoting information sharing about natural capital resources using GIS

Submitted to the United Nations Environment Science division UNEP/GRID-Geneva partnership and the University of Geneva, as partial fulfilment of the requirements for the complementary certificate in geomatics

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Abstract

This report summarises a four months internship which's main goal is to learn and develop knowledge in the field of geographic information services. The first main project focuses on hydrocarbon pollution remediation through the use of simple tools developed with ArcMap 10.6. These tools were further optimised by tweaking the core python code in order to simplify their usage. The second large project involved natural capital data and their geospatial representation. In order to do so, a feasibility study was carried. This work consisted in synthesising and inventorying the available data in order to know define the possible deliverables or what data should be further requested or completed. The final aim of this project was to implement a series of dashboards and story maps. Additionally, the internship involved work on side projects on a punctual basis in order to support the general functioning of the organisation.

Keywords

Geographic Information Systems, Hydrocarbon pollution remediation, Python coding, Natural capital, Dashboard, feasibility study

Résumé

Ce rapport résume un stage de quatre mois dont le but principal est d'apprendre et de développer des connaissances dans le domaine des services d'information géographique. Le premier projet principal porte sur l'assainissement de la pollution aux hydrocarbures grâce à l'utilisation d'outils simples développés avec ArcMap 10.6. Ces outils ont été optimisés en modifiant le code python de base afin de simplifier leur utilisation. Le deuxième grand projet portait sur les données sur le capital naturel et leur représentation géospatiale. Pour ce faire, une étude de faisabilité a été réalisée. Ce travail a consisté à synthétiser et inventorier les données disponibles afin de pouvoir définir les livrables possibles ou les données qui devraient être demandées ou complétées. L'objectif final de ce projet était de mettre en place une série de tableaux de bord et de cartes narratives. De plus, le stage a impliqué un travail ponctuel sur des projets parallèles afin de soutenir le fonctionnement général de l'organisation.

Mots clefs

Systèmes d'information géographique, assainissement des pollutions aux hydrocarbures, codage Python, capital naturel, tableau de bord, étude de faisabilité

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1 Introduction

This report describes the work carried out during a four months internship within the GRID-Geneva partnership. The latter is part of the science division from the United Nations Environmental Department. This internship is a requirement for the obtention of the complementary certificate in geomatics from University of Geneva. The complementary certificate is a 30 ECTS credits diploma focusing on Geographic Information Systems (GIS). The internships accounts for 12 ECTS credits, the remaining credits being contributed by the different lectures. The internship is supposed to last a minimum of two months. The lectures encompass four core branches and two supplemental topic specific lectures.

1.1 United Nations Environmental Program and the UNEP/GRID-Geneva

The United Nations Environmental Program (UNEP) is part of the United Nations Organisation (UNO). It is therefore an international entity that as the name suggests, deals with environmental matters. The UNO was founded in 1945 by 51 states. Today it comprises 193 state members and is headquartered in Manhattan, United States. The main objective of the organisation is to promote peace and international security.

The environmental program of the UNO was founded in 1972 by Mr. Maurice Strong and is headquartered in Nairobi, Kenya. Its main global goal is to care for world scale environmental issues regarding all ecosystems. The UNEP is for instance involved in the development of environmental conventions such as the Minamata convention on mercury. It promotes as well scientific research, it gets involved on natural disasters' topics or environmental governance related matters among many other fields of expertise.

The Global Resource Information Database (GRID) department is part of the science division of the UN Environment which has centres in both Nairobi, Kenya and Geneva, Switzerland (see Figure 1). The GRID focuses mainly on GIS thematics, such as data management, teledetection and automatic data processing in order to produce vital conclusive material, such as maps or data cubes, derived from the aforementioned data, which could be key in the decision-making process. Additionally, the GRID participates with other institutions within UNEP to promote their work through the usage of GIS representation tools. The UNEP/GRID Geneva is a partnership between the Swiss Federal Office the Environment (FOEN), University of Geneva and UNEP. The internship subject of this report was carried in the latter department.

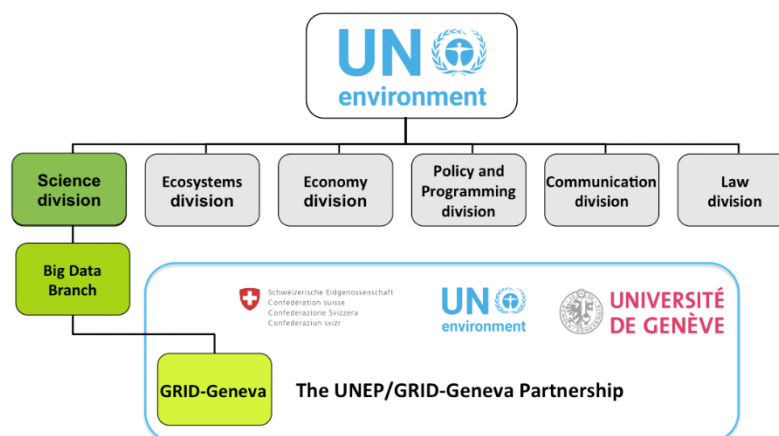


Figure 1: UNEP/GRID-Geneva partnership within UN environment organigram. <https://unepgrid.ch> 2019

Introduction

1.2 Internship objectives

The main project aimed at developing an efficient and sound method to detect and quantify hydrocarbon pollutions in Ogoniland, Nigeria, using Geographic Information Systems.

Ogoniland is a region of the Niger delta situated southeast of Port Harcourt. For decades this area's hydrocarbon resources have been exploited massively, simultaneously extraction infrastructure and exploitation polluting the area. Nowadays, trained Nigerian nationals are at work in the remediation process but lack specific tools or knowledge. This internship focused on developing "easy to use" tools and a working methodology they are free to use. A general technical support "hotline" was as well manned and general advice was as well given such as on the creation of story maps.

The second important part of the internship consisted in a feasibility study for a UNEP organisation called The Economics of Ecosystems and Biodiversity (TEEB). This entity deals with economic analysis of natural resources and their durable usage, all around the world.

This feasibility study included the review of some of the recently published reports from this organisation and the analysis of the relevant associated data and their geospatial display possibilities. The aim being to represent in the best way possible on the GIS platform MapX (series of dashboards with or without sliders, story maps), the outcome of the different TEEB projects. The long-term objective would be for MapX to be the unique go-to GIS display platform of TEEB.

The additional work consisted in punctual help on other GIS related matters. This included attending lectures and assisting fellow students, participating in pilot projects brainstorming meetings, document translations and updating maps on the UNEP/GRID-Geneva's geospatial information monitoring tool, mapX.

MapX is a geospatial data platform for the sustainable management and monitoring of natural resources. It was developed by UNEP/GRID-Geneva in partnership with UN Environment and the World Bank. This open access platform allows the sharing, analysis and visualization of spatial data from the United Nations' different units (see Figure 2). It enables key decision-making processes by grouping the relevant information into one single entity with easy to use representation tools (dashboards and story maps).

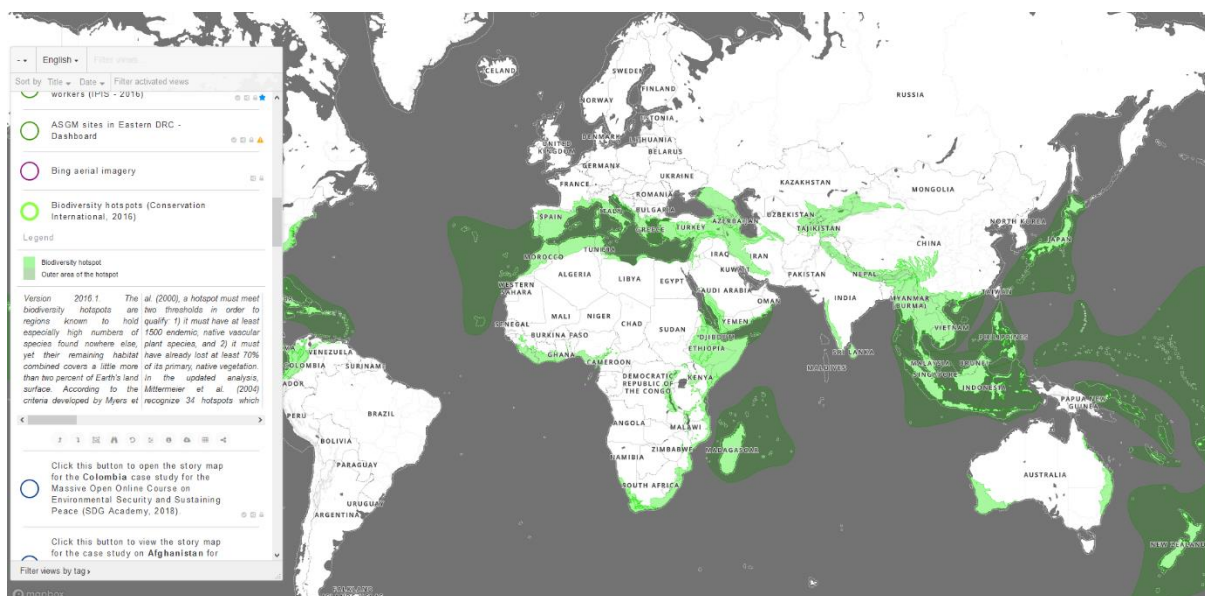


Figure 2: Map example from the MapX platform. Here is the representation of Biodiversity hotspots (Conservation international 2016). <https://app.mapx.org> 2019

2 HYPREP Hydrocarbon Pollution and Remediation Project

2.1 Introduction and problematic

This project is related to hydrocarbon pollution in Ogoniland, River state, southern Nigeria (see Figure 3). In this part of the Niger delta, oil production has been ongoing since the late 1950s and stretched till 1993. The company exploiting the resources was the Shell Petroleum Development company (Nigeria) Ltd (SPDC) a joint venture between the Nigerian National Petroleum Company (NNPC), Shell International, Elf and Agip.

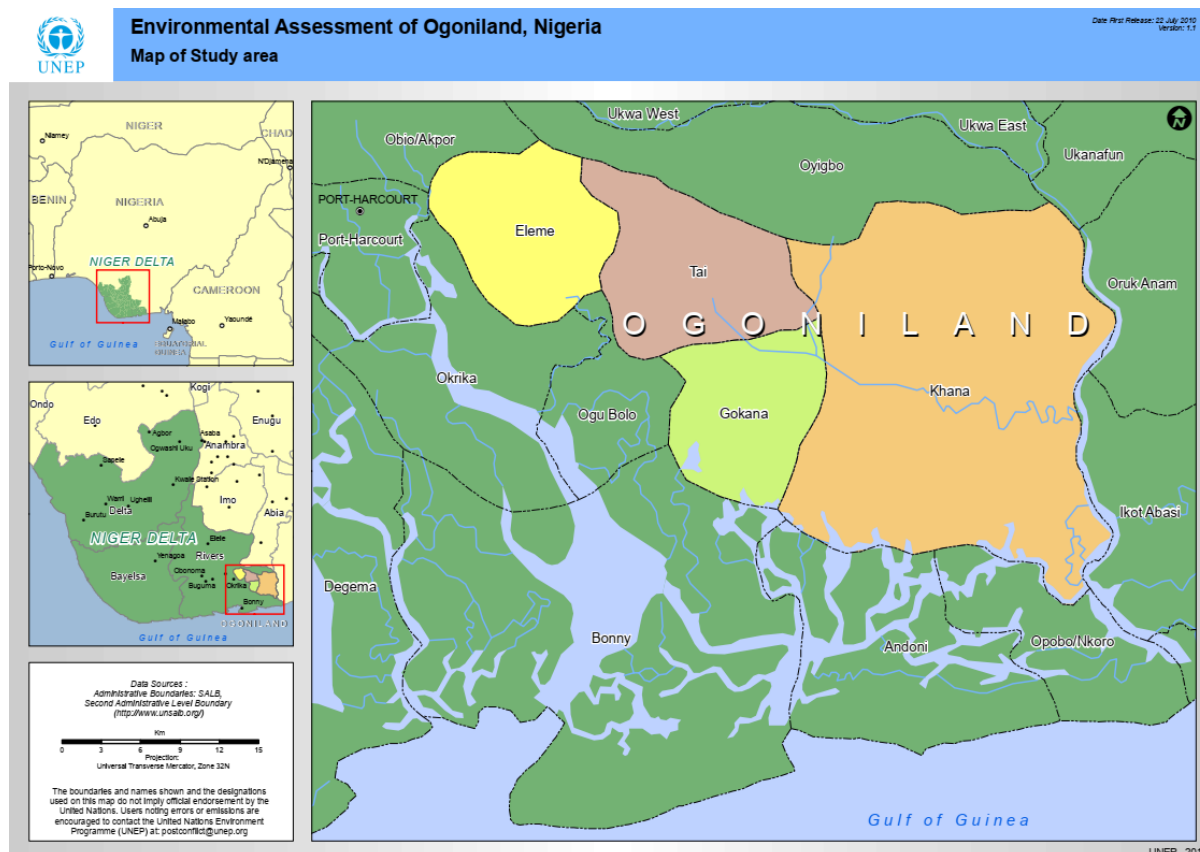


Figure 3: Ogoniland geographic situation in Nigeria. <https://www.unenvironment.org> 2019

This exploitation created numerous environmental issues prior, during and after exploitation. Polluting activities preceding exploitation involved land clearances for multiple reasons (seismic survey, access, infrastructure building, etc.), construction work and drilling. Polluting activities during exploitation encompasses spillages (accidents, poor infrastructure maintenance, looting), spoilt water discharge, gas flaring, or disposal of tailings and drilling mud. Even though oil exploitation has come to an end in Ogoniland, pipelines are still used and therefore, pollutions still occur through the process of looting (based on degradation of oil conducting pipelines), illegal refining and accidental spillages due to lack maintenance and control of existing infrastructure.

Ogoniland was and still is a region of the Niger delta which is strongly contaminated with hydrocarbons but not only. Drilling mud containing baryte (a radioactive mineral) and drilling tailings are often disposed of in an environmentally unfriendly manner.

In 2006 UNEP received a request from the Federal Government of Nigeria to conduct an assessment of the impact both environmental and health related of the oil exploitation in Ogoniland. In 2011 a full report was published distinguishing 69 sites for further detailed investigations. On all sites, pollution and therefor threat to living beings was proven to different extents. Since 2011, progress has been

made, noticeably by the creation of the Hydrocarbon Pollution and Remediation Program (HYPREP) which's primary goal is to take care of the oil spillages plaguing Ogoniland and its people.

UNEP got further involved by training competent Nigerian nationals in Switzerland on subjects such as GIS tools, or polluted site investigation technics. As part of the continuation of UNEP's contribution to that ongoing process, the scope of the internship was to further strengthen the capabilities of local teams in the investigation of polluted sites on the basis of GIS related tools.

2.2 Best practice Concept

2.2.1 Definition

The idea behind the best practice concept is to simplify the investigation and remediation activities. Usually polluted sites are large, and this can amount to an important quantity of work especially in intensely polluted areas. The concept relies on the general polluted site investigation and remediation practices in vigour notably in Switzerland (see OFEV and OFEFP guide documents in bibliography) and general geological/hydrogeological know-how. Geographic Information Systems (GIS) tools that can simplify or speed up processes were utilised, and the author's personal professional knowledge was put to contribution as well.

The practice relies on 4 different steps (OFEV 2017, OFEFP 2000, 2001). Step 1 is the site identification which includes gathering relevant information through what is called a historical investigation. The second step consists in gathering the missing information such as underground water flowing direction through what is called a technical investigation. The third step consists in evaluating the pollution levels at depth but in terms of surface too. This step is known as the detailed investigation. This can usually be combined with Step 2. Step 4 which is the last step, consists in the remediation process, but this topic will not be covered in this report. This can be resumed as below.

1. Historical investigation
2. Technical investigation
3. Detailed investigation
4. Remediation

In the following chapters, in order to develop and test the tools created, a made-up dataset was used. locations are all situated in the region southeast of Port Harcourt, Nigeria. Pollution concentrations where based on a scale of values from the Ogoniland 2011 Assessment from UNEP.

2.2.2 Historical investigation – Site definition



Not all sites are to be treated the same way in a remediation process. Urgency levels are different according to the incidents that occurred, and the activities carried over the years. In order to get a full understanding, prior investigation is fundamental. This starts with historical researches. The site operating company records can provide information on site layout, incidents, utilisation and so forth. Local witnesses provide as well supplemental useful information that may have been omitted by the owner or user of the site. The information looked for are:

1. Site boundary
2. Site layout
3. Site usage and activities
4. Timeframe of usage and activities
5. Dangerous substances used and quantities if any
6. Containment measures of dangerous substances if any
7. Incidents if any
8. Geology

HYPREP Hydrocarbon Pollution and Remediation Project

Therefore, if the tool is to be used, everything should be done using this system or the raw code must be modified in order to accommodate another coordinate system.

Once the project and the geodatabase are created, a first feature class (polygon) should be created in the geodatabase (see Figure 5). This feature class should be a polygon type feature class and the name should be "Sites". This feature class will contain at least 1 field to start with (not including "OBJECTID" and "SHAPE" which are created by default). This field will be called "Name", which will be filled with the name of the site within the region. More fields can be added later if necessary. Once the "Sites" feature class has been created, an editing session can be started, and sites can be drawn. For every site drawn, the "Name" field is completed. This is performed in an editing session.

It is important that the polygon delineating the site be set as the processing extent for further computational work and it must be changed again for any other work on another site (see Figure 6). The site must be selected (select features ) and exported (export data, right click on feature class ) in order to be used as processing extent.

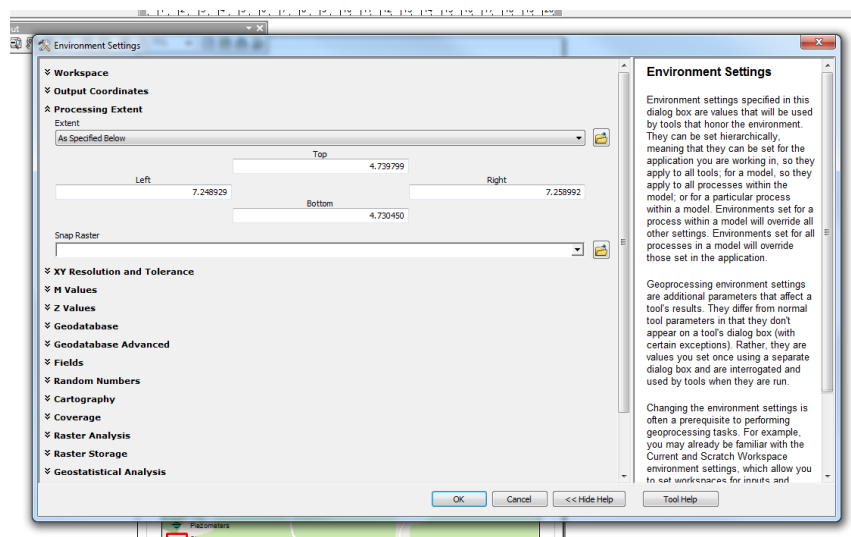


Figure 6: Setting of the processing extent in ArcMap 10.6

The processing extent can be found under "Geoprocessing" then "environment" (see Figure 7). This limits the computations within the site and does not spread the computed results over unwanted areas and requisitioning computational capacity that could be required elsewhere (<http://desktop.arcgis.com/en/arcmap/10.6/tools/environments/output-extent.htm>).

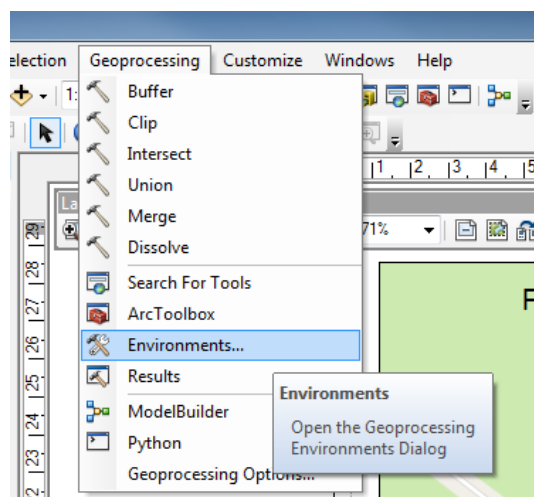


Figure 7: Path to setting the Processing extent in ArcMap 10.6

2.2.3 Technical investigation part 1 – Water monitoring

Hydrocarbon pollution is mobile. It moves according to water flow under the surface and to meteoric waters. Therefore, it is crucial to understand water movements in the ground before even starting to sample the site in search for pollution.

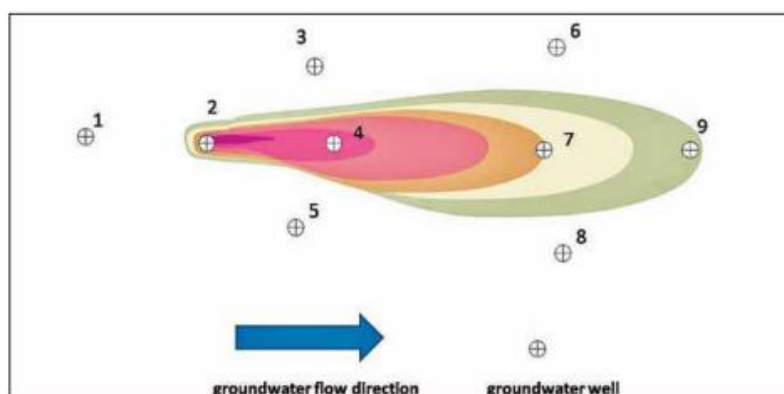
In order to understand underground water flows, a water monitoring campaign has to be performed beforehand. This monitoring is done using piezometers in order to model underground water flows. According to the area of the site a certain number of piezometers have to be sunken into the ground. As a rule of thumb one piezometer can suffice for every 200 to 400 m². This is also a question of time and budget. Once sunken, water levels must be allowed to get back to equilibrium since sinking the piezometers changes the pressure system below the surface. Water monitoring must then be performed over a couple of weeks in order to understand the underground water flow system. Depending on the geology the amount of time should not exceed a couple of months since the piezometers can be clogged with clays for instance rendering the water levels recorded completely unreliable.

Water monitoring consists in recording the water levels regularly in the piezometers. The levels below the ground are recorded in a table along with the date, the coordinates of the piezometers and the piezometer edge altitude (see example in Table 1 below).

Table 1: Piezometer record example in excel (purpose made up example).

Piezo Ident	X coordinate [Degrees]	Y Coordinate [Degrees]	Piezometer edge altitude [m]	Water level below piezometer edge [m]	Water level altitude [m]
OGO1	7.249992	4.737256	10.3	5.2	5.1
OGO2	7.254130	4.735331	10.1	5.6	4.5
OGO3	7.249993	4.731011	9.9	5.8	4.1
OGO4	7.257305	4.731952	10.4	5.1	5.3

With this information, water isohypses can be drawn using a purpose developed Tool called “Groundwater simulation” tool. This tool, which is actually a script in ArcGIS, enables to compute and represent in which direction the underground water flows and understand where the pollution plume might be or might have been (see Figure 8). The tool should not be considered as the ultimate truth considering that it is based on interpolations. In the current approach Spherical Gaussian Kriging is used (Peeters et al. 2010). The kriging interpolation method is very often used even though it has some flaws when regarding large areas with a limited number of piezometers. Although at a standard site



scale this method is perfectly valid. However local hydrogeological and geological subtleties have to be taken into account when observing the results in order to validate them. The reality can be approached but never fully reached. One can only work with the least wrong solution.

Figure 8: Pollution plume positioning and displacement according to groundwater flow direction. Environmental assessment of Ogoniland, 2011

2.2.3.1 Groundwater simulation – principles and user guide

The “Groundwater simulation” tool consists itself of a combination of different tools put together. The first step prior to using the tool consists in specifying the inputs. The coordinates in the piezometer table will be extracted and will serve to the creation of a feature class (point) with a transitional step. The following step will interrogate the water altitudes in the different locations and interpolate the underground water flow map in between the piezometers using a kriging method as mentioned earlier. Based on that map, isohypses and flow direction vectors will be drawn giving a visual understanding of the underground water flowing process (see Figure 9).

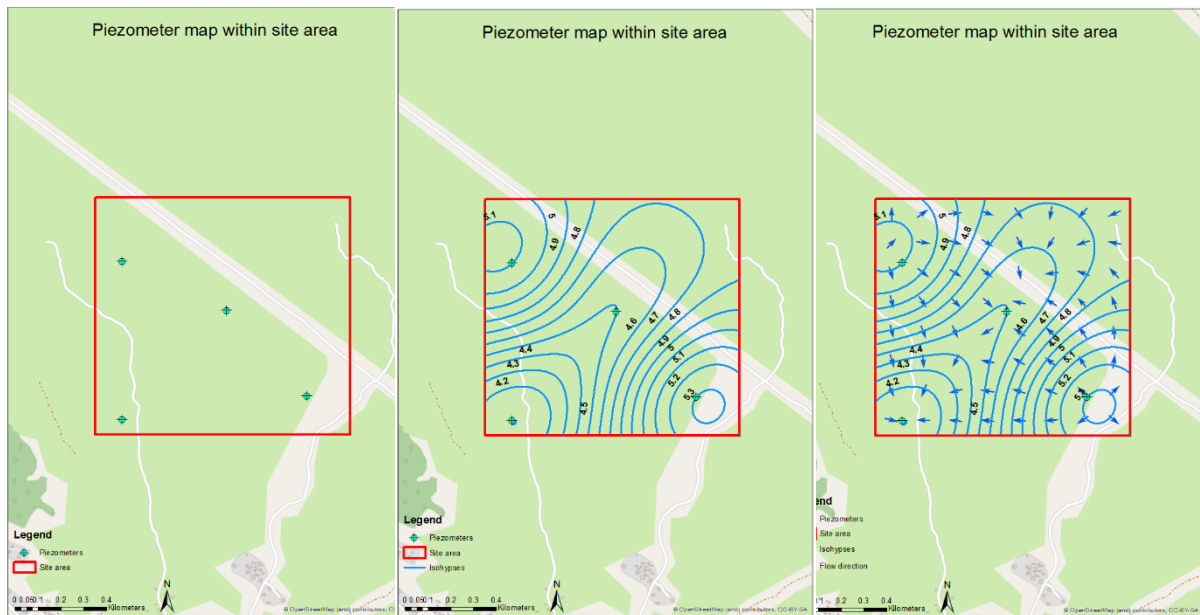


Figure 9: Left, site area with piezometer positions. Centre, added isohypses. Right, added flow direction.

The “Groundwater simulation” tool prior to usage must be saved in a toolbox itself saved into the geodatabase created earlier. This can be done from the Catalog pane on the right of the window in ArcMap (see Figure 10). The script of the “Groundwater simulation” tool can then be saved in it.

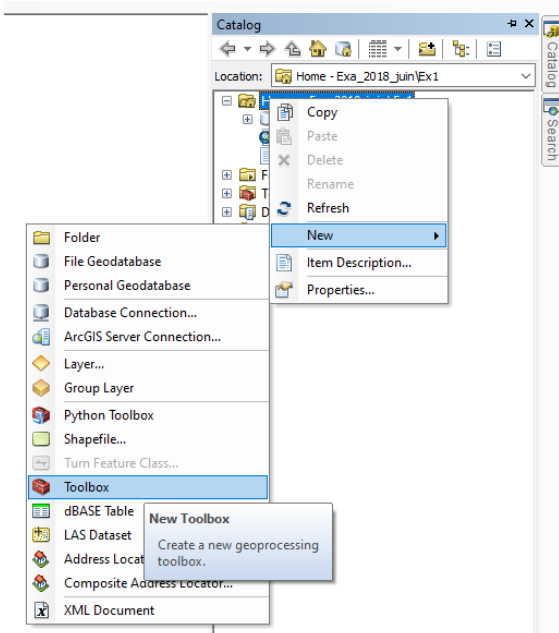


Figure 10: Creation of a new Toolbox in ArcMap 10.6

HYPREP Hydrocarbon Pollution and Remediation Project

Each piezometer must have the following information about it:

- Date of entry into function of the piezometer and decommissioning if relevant
- Name
- X and Y coordinates
- The altitude of the upper edge of the piezometer (GPS, Google earth, DEM)

When monitoring water levels, two more values are obtained. The first is by directly measuring the distance from the upper edge of the piezometer to the water and the second, derived from the difference between the attitude of the upper edge and the depth of the water thus giving the altitude of the water level. This can be reported and calculated in an excel file. The data should then be saved as a CSV file exactly how it is seen in Table 2 below in order to use the data with the “Groundwater simulation” tool. The coordinates should be as well WGS84 compliant and should be entered in the table as shown. It is important to make sure that no “invisible” data is in the CSV file such as “;” when saving the CSV from an excel sheet. It is advised to selected cells below the data and tap the “delete” button in order to make sure nothing prevents the piezometer tool from working properly. The water level altitude can be substituted by the depth of water when the topography is completely flat.

Table 2: Piezometer table from CSV file. (purpose example) Only the data seen below should be in the CSV file.

Piezo Ident	X coordinate	Y Coordinate	Piezo edge altitude	Water level below piezo edge	Water level altitude
OGO1	7.249992	4.737256	10.3	5.2	5.1
OGO2	7.25413	4.735331	10.1	5.6	4.5
OGO3	7.249993	4.731011	9.9	5.8	4.1
OGO4	7.257305	4.731952	10.4	5.1	5.3

In the project on ArcMap, from the Catalog pane, the “Groundwater simulation” tool (script) is called up from the toolbox in the right-hand pane (see Figure 11).

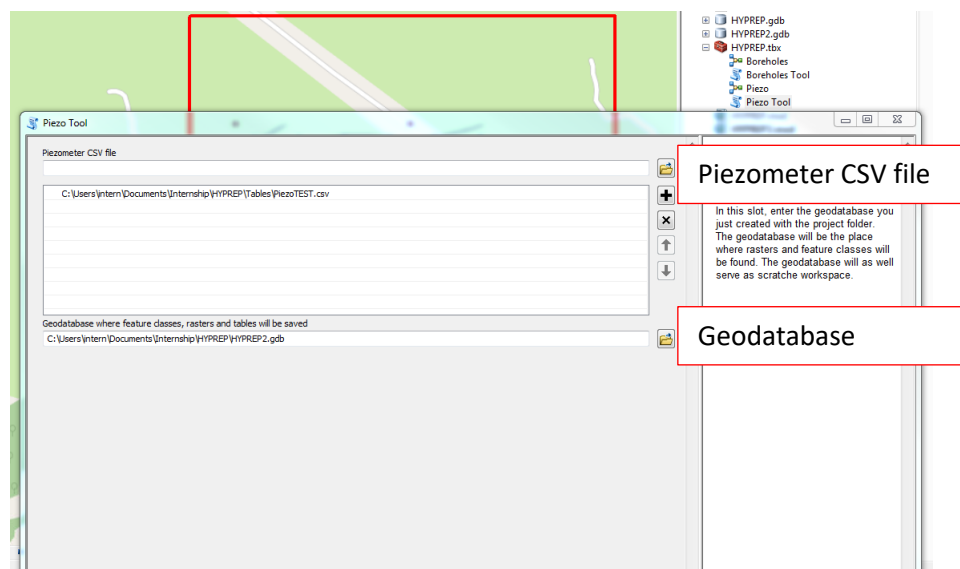


Figure 11: the “Groundwater simulation” tool found in a toolbox itself located in the project folder. In this case the toolbox and the folder are called “HYPREP”

The tool is relatively fast (approximately 10 seoncds) but depends on the computer’s capacity and the quantity of data to be processed. The CSV file must be added in the top slot and the geodatabase in the bottom slot of the tool as shown above in Figure 11. Once this is done, simply start the

computation process by clicking on “OK”. Once complete, the “piezomap” and the “Contour_map” feature classes and the “Flow_direction” raster must be added to the project map. The symbology has then to be adapted. Regarding the contour map, the labels should be activated by right-clicking on the feature class in the left pane (see Figure 12) and the labels must show the field “Contour” (see Figure 13) in order for the isohypsies to mean anything.

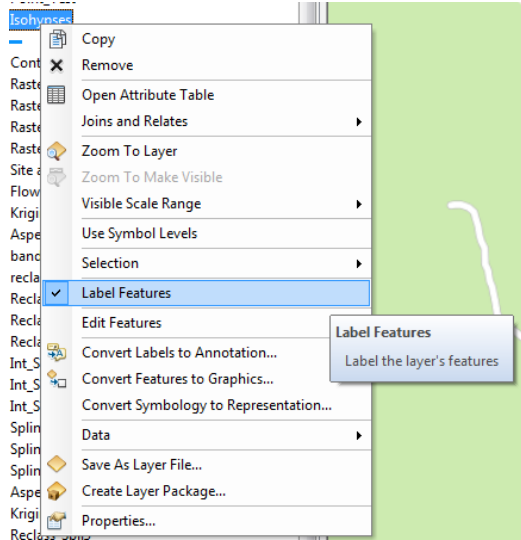


Figure 12: Activation of labels

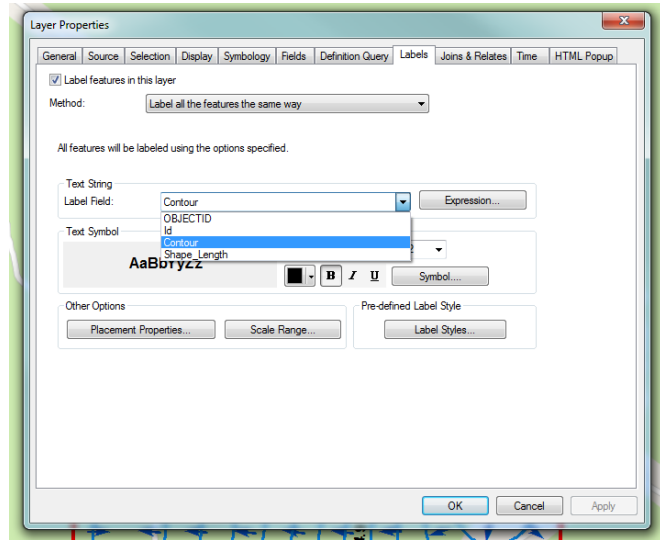


Figure 13: Choice of label field

The symbology of the flow direction map must show the vector field and the symbol must be a single arrow (see Figure 14). Further customisation is fully personal. Maps can then be printed from the three layers produced and customised further. An example is visible below. In this example the names were changed. “piezoMap” becomes “Piezometers”, “Contour_Map” becomes “Isohypsae” and “Flow_direction” becomes “Flow direction” in order to produce a proper and comprehensive map (see Figure 16). Furthermore, in that example, the site area is as well displayed with a bright red line contour.

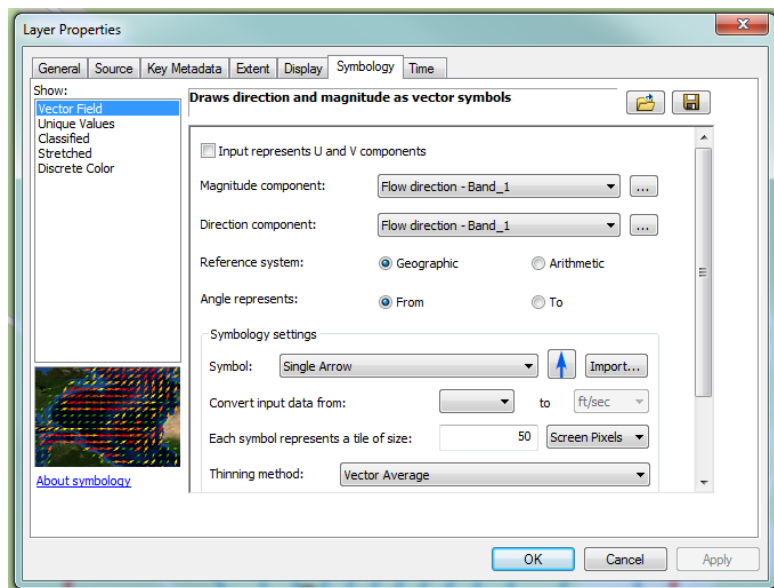


Figure 14: Symbology change of the "Flow_direction" raster from "stretched" (default) to "Vector Field"

The code for the tool can be found in the annexes. It cannot be emphasised enough that for the tool to work properly, the recommendations given above must be followed rigorously. To sum up, the CSV files must respect the format of Table 2, the “Groundwater simulation” tool must be in a toolbox itself in a folder or in a geodatabase. The latter contains as well the MXD file and the GDB database file of the project (see Figure 15). The coordinates must be WGS84 coordinates.

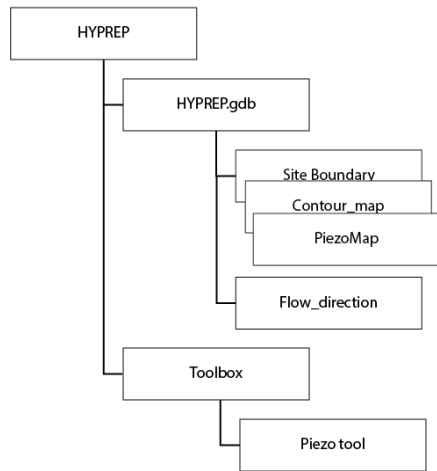


Figure 15: “Groundwater simulation” tool project folder tree structure as used in this report.

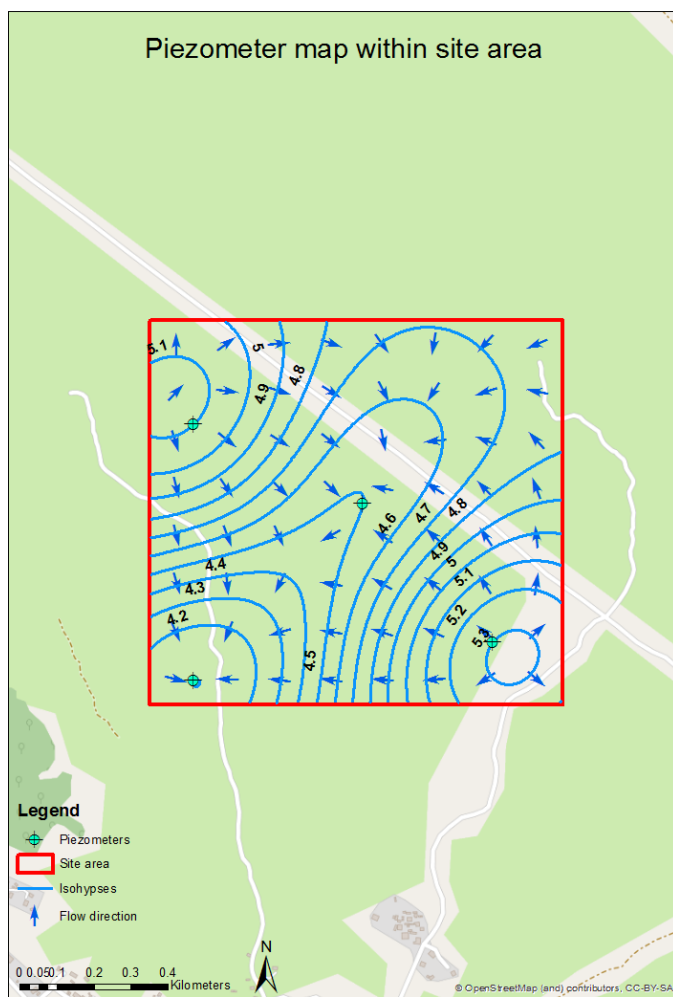


Figure 16: Map example of piezometers, Isohypses, and flow direction vectors as obtained from a CSV file processed through the “Groundwater simulation” tool

2.2.3.2 Outcome of Groundwater simulation tool

The tool provides the groundwater flow maps. This information can be useful in the case of a site remediation but could be used as well when investigating for drinking water sources or for agricultural irrigation water for instance.

In the current case, the groundwater map helps positioning the sampling locations (see Figure 17). The hydrocarbon pollution as well as other pollutants such as heavy metals can be mobilised by circulating water and meteoric water. If the underground water flows southward for instance, sample uptake locations have to be focused on a southerly direction from the pollution source. The depth of the water is crucial too. Usually it is good to reach the underground water when boring to make sure that potential drinking water has not been affected. It can be relevant to sample the water when sinking the piezometers. The water samples retain valuable information such as different pollution levels or oxygen saturation, conductivity, etc.

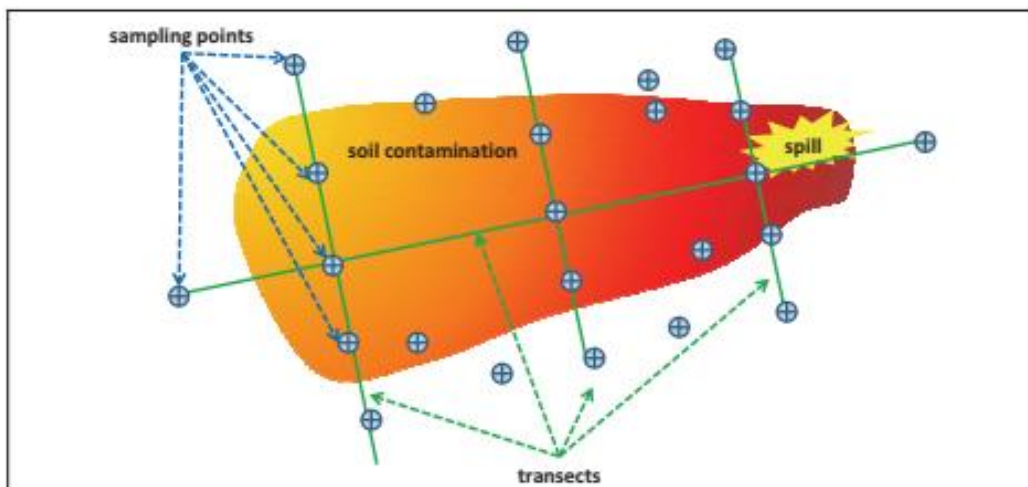


Figure 17: Soil sampling Boreholes and locations. Environmental assessment of Ogoniland, 2011

2.2.4 Technical investigation part 2 – Soil monitoring

Soil monitoring is the next step of the process in the technical investigation. It is a task that can only be performed once the water monitoring has been done. If the water monitoring step is skipped, it is very difficult to predict in which direction and to which depth the pollution might have migrated. According to the water levels recorded in the previous steps, the sampling locations are established and placed on the site map. It is important to aim downstream of the groundwater flow direction, but a sampling location upstream is not to be neglected either, as part of a control mechanism. When it comes to natural systems, incongruous findings are always possible. As well as the upstream reach, the pollution plume edges must be looked for. Ideally the ground is drilled in order to sample and this is the terminology used in this report. However, a hand-held auger is perfectly valid but simply not at the same depth scale.

The aim of soil monitoring is to have sampling locations placed around the plume where Total Petroleum Hydrocarbons (TPH) or any pollutant levels are generally low and, in the centre, where they are high. This means the pollution plume is fully constrained. One dimension is still missing however, and it is the depth. The sampling locations situated directly in the pollution plume are expected to record high TPH concentrations up to a certain depth beyond which TPH concentrations will drop. This drop signals the base of the pollution and gives an indication of the depth to which remediation processes have to be carried out.

The sampling grid is established upon water flow results interpretation but as well according to all the information gathered prior. Not all types of pollutions are to be tackled the same way. In the following chapter a tool is presented which is able to illustrate the pollution plume both over a surface and at depth. The tool produces as well statistical data. Pollution levels are categorised and from these pollution categories, volumes are calculated from the surface and depth data. Surface is derived from the site dimensions reported earlier. Depth information comes from the sampling data collected. The categories are based on the remediation close out values from the Environmental Guideline and Standards for the Petroleum Industries in Nigeria (EGASPIN) and Remediation Management System (RMS) from the Shell Petroleum Development Company (SPDC) as can be observed in Table 7.

This tool was developed in order to simplify work and to have representative data to use and to enable critical decision making. From a CSV file containing sampling TPH levels in different locations and at different depths, pollution levels heat maps are generated. Each map is indicative of a level/depth and all combined together are indicative of the whole depth (see Figure 18).

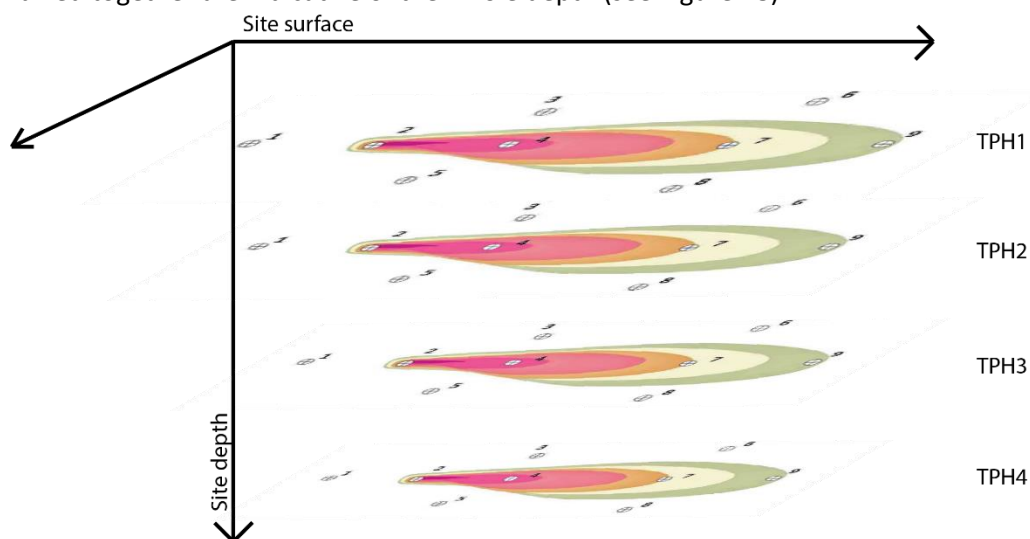


Figure 18: Depiction of various made up heat maps at different depths. This figure highlights as well the surface and the depth of contamination within a site.

In order to generate those different maps, the first step is to collect data in the field and to report them in a table. An example is given in Table 3 below. The most important information is the name of the location, the date of sampling, and the coordinates. In this example “TPH*” columns represent TPH concentrations at different levels/depths (see Figure 18). The Thickness for clarity purposes is reported in another table.

Table 3: Sampling record example in excel table (purpose made up example).

Sampling location Ident	X coordinate [degrees]	Y Coordinate [degrees]	altitude [m]	TPH1 [mg/kg]	TPH2 [mg/kg]	TPH3 [mg/kg]	TPH4 [mg/kg]
OGO BH1	7.252092	4.734336	10	7000	5000	3000	7000
OGO BH2	7.25672	4.739731	9	6800	4800	2800	6800
OGO BH3	7.249544	4.733145	9.5	6600	4600		6600
OGO BH4	7.253224	4.732685	10.5	6400	4400	2400	4400
OGO BH5	7.253932	4.731573	9		4200	2200	4200
OGO BH6	7.253428	4.735861	10	6000	4000	2000	4000
OGO BH7	7.252505	4.737079	10	5800	3800	1800	3800
OGO BH8	7.255005	4.734781	10.5	5600			
OGO BH9	7.249467	4.739731	9.5	5400	3400	1400	1400
OGO BH10	7.25672	4.735508	9.5	5200	3200	1200	1200

The principles of Steno (1916) are hereby applied in order to simplify processes:

1. Law of superposition
2. Principle of original horizontality
3. Principle of lateral continuity
4. Principle of cross cutting relationships

Namely the first and third principles come into consideration. The first law states that sedimentation obeys to superposition laws meaning that young material overlays older material. The third principle states that a layer spreads laterally forever unless it is limited physically. In other words, the polluted level TPH1 for instance, spreads at the same depth over all the sampling locations and lies above level/depth TPH2. This should be kept in mind when entering data in the table and when sampling in the field.

From the pollution concentrations, heat maps are created for every TPH* level. They are interpolation-based maps representing the probable pollution distribution based on the sample locations and TPH concentrations. The interpolation is a spline tension algorithm. This sort of calculation is well suited for smoothly changing values such as pollution concentrations (Bixiong et al. 2006). Just like in the case of water levels, the heat maps are hypothetical and only reflect one possible reality. From these heat maps, volumes are computed in order to evaluate the extent of the pollution, its severity.

2.2.4.1 TPH Pollution Simulation tool - principles and user guide

The project skeleton is the same as for the water level computations. The “TPH Pollution Simulation” tool is saved within the toolbox previously created and used from there. The tool computes a first temporary layer containing the sampling locations. Next, the temporary layer is processed into a point feature class on which further work is carried (see Figure 19).

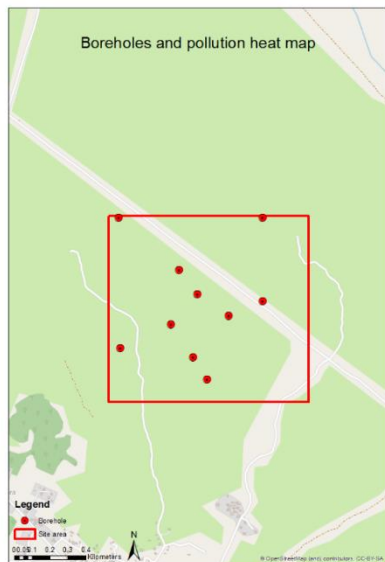


Figure 19: Map depicting the sampling locations within the site area.

The sampling information at depth is then used to interpolate pollution concentrations over the whole site by interpolation as discussed previously (see Figure 20). This data is further converted into a pollution classified map (see Figure 21). For every pollution class, a total volume is computed based on the surface occupied and the thickness of the concerned TPH level. All the volumes [m³] are then exported into an excel file (see Table 4). There is one map and excel file for each TPH level recorded (see Figure 22). Finally, the tool computes a summary map with the pollution level classes of all TPH maps summed up to illustrate a severity map. The higher the sum, the worse the pollution in terms of concentration but as well in terms of depth.

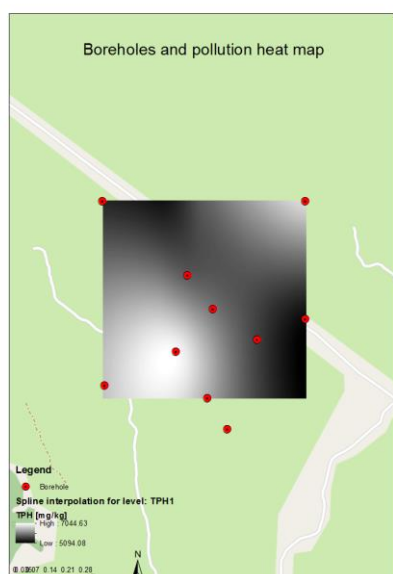


Figure 20: Spline interpolation map of TPH1.

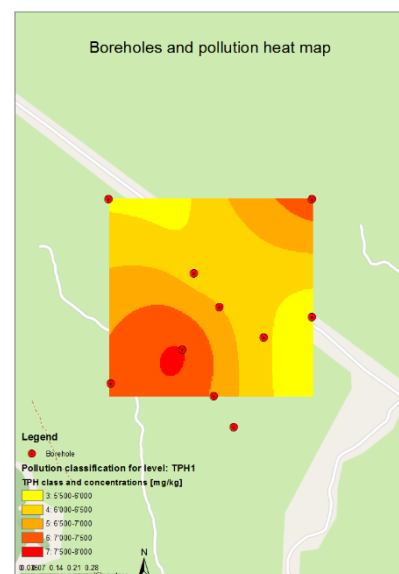


Figure 21: Classification map of level TPH1.

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Table 4: Volume excel table from level TPH1. gridcode is the class of pollution level. FREQUENCY represents the number of distinct areas with that pollution level and the SUM_Volume is the total volume of all these areas.

OBJECTID	gridcode	FREQUENCY	SUM_Volume
1	3	2	138149.0916
2	4	1	388869.7423
3	5	2	214965.932
4	6	2	194172.4558
5	7	1	13641.37677

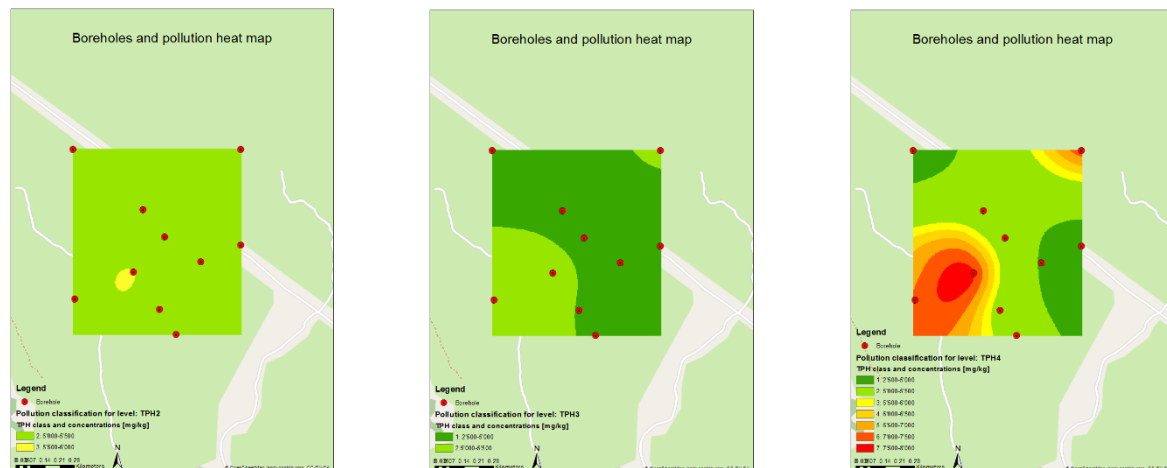


Figure 22: Classification maps of TPH2 to TPH4.

Each sampling location must have the following information about it:

- Date of sample uptake
- Name
- X and Y coordinates
- The altitude of the sampling location
- The depth at which samples are taken

During the sample uptake, the associated depth reported provides the information about the altitude at which the sample is situated further enabling to establish the thicknesses of all the levels. All the data should be saved as a CSV file in the exact manner as seen in Table 5 below in order to use the data with the “TPH Pollution Simulation” tool. The coordinates should be as well WGS84 compliant and should be entered in the table as shown. It is important to make sure that no “invisible” data is in the CSV file such as “;” when saving the CSV from an excel sheet. It is advised to selected cells below the data and tap the “delete” button in order to make sure nothing prevents the “TPH Pollution Simulation” tool from working properly. If no sample has been taken, the cell must be left empty or filled with zeros.

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Table 5: Borehole table from CSV file. (purpose example) Only the data seen below should be in the CSV file.

Borehole Ident	X coordinate	Y Coordinate	BH edge altitude	TPH1	TPH2	TPH3	TPH4
OGO BH1	7.252092	4.734336	10	7000	5000	3000	7000
OGO BH2	7.25672	4.739731	9	6800	4800	2800	6800
OGO BH3	7.249544	4.733145	9.5	6600	4600		6600
OGO BH4	7.253224	4.732685	10.5	6400	4400	2400	4400
OGO BH5	7.253932	4.731573	9		4200	2200	4200
OGO BH6	7.253428	4.735861	10	6000	4000	2000	4000
OGO BH7	7.252505	4.737079	10	5800	3800	1800	3800
OGO BH8	7.255005	4.734781	10.5	5600			
OGO BH9	7.249467	4.739731	9.5	5400	3400	1400	1400
OGO BH10	7.25672	4.735508	9.5	5200	3200	1200	1200

Additionally, a thickness file must be created and must look exactly like in Table 6 below. These thicknesses will enable the volume computation: $\text{Sum of class area} \times \text{class thickness} = \text{Volume}$

Table 6: Thickness table.

TPH1	TPH2	TPH3	TPH4
1.5	2.0	1.0	3.5

In the project on ArcMap, from the Catalog pane, the “TPH Pollution Simulation” tool (script) is called up from the toolbox in the right-hand pane (see Figure 23).

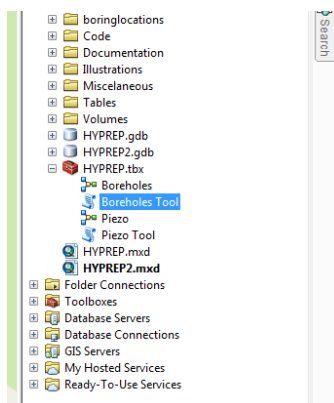


Figure 23: View of the right-hand pane. Location of the “TPH Pollution Simulation” tool in the toolbox itself inside the project folder.

The tool can take some time to compute due to the many calculations taking place (60 seconds), but this depends on the computer’s capacity and the quantity of data to be processed (number of sampling locations and TPH levels) as well. The CSV file must be added in the top slot, then the geodatabase in the slot below followed by the Folder location for the volume excel files and all at the bottom comes the thickness CSV file (see Figure 24). Once this is done, simply start the computation process by clicking on “OK”.

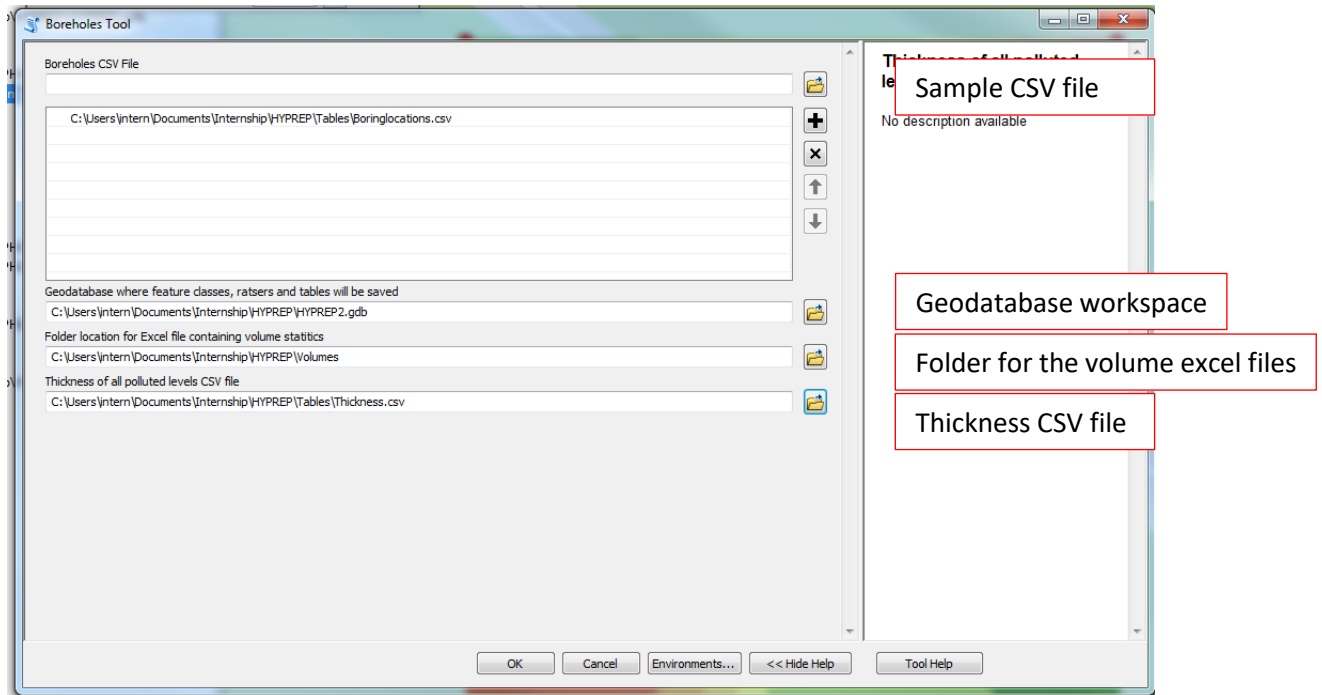


Figure 24: “TPH Pollution Simulation” tool parameter window. The different slot entries are detailed.

Once complete, the “Borehole” and the “PolygonTPH*” feature classes as well as the “SumTPH” raster must be added to the map. The symbology has then to be adapted. Any symbol that suits the user can be chosen for the boreholes. The PolygonTPH* layers are to be symbolized by unique values for each pollution class and the colours should be graduated from green to red accordingly (low TPH to high TPH concentrations). The classes are as seen in the Table 7 below. The Labels must also be changed in order to represent properly the information in the maps created. The sum of all TPH class maps’ symbology can be adapted according to needs and the values obtained. Figure 26, below is just the result of the example in this report.

Table 7: Classification details.

Class number	Range (TPH [mg/kg])	Colour suggestion
0	0-3'000 (3'000 = RMS close out value)	
1	2'500-5'000 (5'000 = EGASPIN close out value)	
2	5'000-5'500	
3	5'500-6'000	
4	6'000-6'500	
5	6'500-7'000	
6	7'500-8'000	
7	8'000-8'500	
8	8'500-9'000	
9	9'000+	

The code for the tool can be found in the annexes. It cannot be emphasised enough that for the tool to work properly, the recommendations given above must be followed rigorously. To resume them, the CSV files must respect the format Table 2, the “TPH Pollution Simulation” tool must be in a toolbox itself in a folder or within the geodatabase. The latter contains as well the MXD file and the GDB database file of the project (see Figure 25). The coordinates must be WGS84 coordinates.

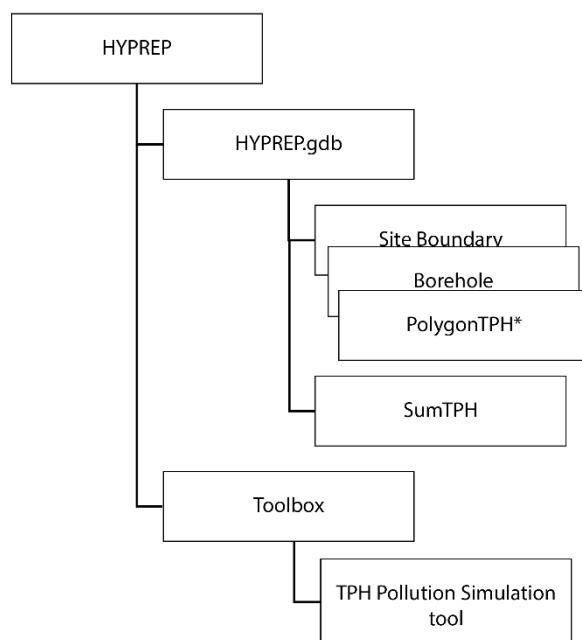


Figure 25: TPH Pollution Simulation tool project folder tree structure as used in this report.

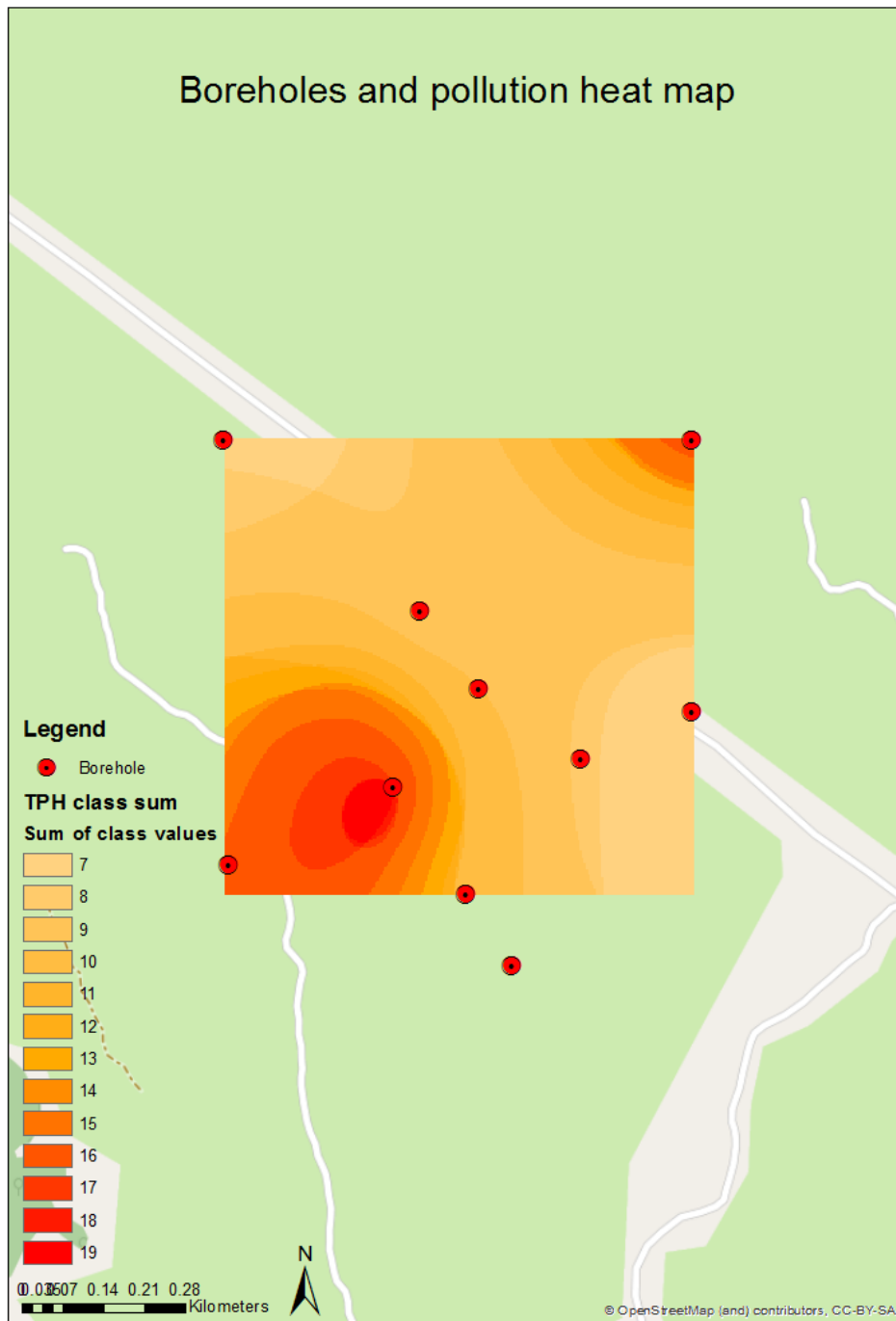


Figure 26: Sum of all for TPH class maps.

2.2.4.2 Outcome from the TPH Pollution Simulation tool

This tool provides useful information in the scope of the technical investigation but as well the detailed investigation. Usually the detailed investigation follows according to the pollution found. A site can be polluted but below the pollution levels necessitating remediation works and therefore nor further work will be carried.

Results are visual and rapidly comprehensible in order to grasp the magnitude of the pollution. Often numbers can hide information. For instance, pollution levels can be low but above EGASPIN standards of remediation close out, but the pollution is very wide spread, or deep.

2.3 Story maps

2.3.1 Introduction

A story map is an interactive and communication tool enabling the creator to share a content with friends, colleagues or even the world. A story map as it names states, tells stories using illustrative material such as maps but as well photos, weblinks, videos or text. The story is unveiled through a series of slides, pages or maps. Each of those pages is usually represented by an illustration as well as some explicative text. It is like watching a documentary but where the information is available as a text, a plot, or an image with the support from a map for instance.

It can be useful to rely on maps to describe a story. As a matter of fact, geography is very important in order for the readers mind to understand the mechanics behind the narration. Maps can be taken as is from internet as ready basemaps or can be fully created in order to reflect the exact mind of the creator. The story map can be solely entertaining, but it can be educative, or a communication mean. It can be as well the base of decision-making processes.

In the following report, a story map was created using ArcGIS online and ArcMap 10.6.

2.3.2 HYPREP story map

In the scope of the HYPREP project, a succinct story map was created as an example of the capacities of such a communication support. The HYPREP personnel have an impressive amount of data and documentation. A large proportion of the documentation are photographic illustrations that can be used in a story map.

In order to demonstrate story map possibilities, photos from the summer 2019 HYPREP visit to Switzerland were used and a purpose map created. The story begins in Port Harcourt and surroundings, Nigeria and ends up in Switzerland on the outskirts of Spiez. Seven pages were created making use of the photos taken during the HYPREP visit. The story simply follows the journey of the people involved and the map points out the geographic positions during that journey.

2.3.2.1 The story

Good communication resumes itself to a good idea. Therefore, the story is crucial. Before starting to create anything, it is important to think about what is to be shown and in what way. For instance, a holiday and a business trip aren't told the same way. If pictures are laid out without coherence it shows a lack of professionalism and the story loses interest. Thus, it can be a good idea to start with a summary of the story as a text.

The story must be structured, either in terms of activities, locations, dates etc. Each of the different entities within the structure can be considered as a page of the future story map. For every page, an illustration will complement the text whether it is a photo, a map, a plot or even a video. This is a dynamic way of working. In other words, if the right photo can't be found, it can be useful to change the text in order to fill in for the lack of photos or vice versa.

2.3.2.2 The photos

Creation possibilities are infinite. In order to keep things simple, photos can be chosen while writing the core text of the story or after. They should be representative of a particular situation without being too precise either. That depends of the story's length. If pictures are very specific, the story goes into details and it becomes lengthy. If pictures are too general, the story becomes short and vague.

It is important that the pictures used have all the necessary information, namely: locations, dates, author. From the pictures and the text, the different pages are then created. Photos must have a legend. In that legend, there is a small description of the picture and the necessary information

mentioned above. The location of the picture can however be complemented with the map instead of being in the legend.

2.3.2.3 The map

The map has a key role. Geographical information is very important in order to give echo to the text and the pictures. It has a central part in the case of journey for instance. It is slightly less relevant in a story taking place in one sole location with exception of situating the action in the first pages of the story. Maps can be of different sorts. Basemaps are readily available as is but can be created as well.

A world map can be zoomed in onto the locations. It is as well possible to create feature classes in ArcMap in order to customise the maps with the different points of interest (point feature class) for instance rather than using zooms on existing maps. Customised maps can include all sorts of additional information. They can depict borders, rivers, roads for instance (line feature class). They can represent countries, basins or working sites (polygon feature class) for instance.

2.3.3 Example story map in detail

2.3.3.1 Basemap

In order to situate the story of HYPREP personnel's journey, a custom map was created. It is based on the world map from open street map and was created in ArcGIS online. At first the main different places visited by the group of people were listed. These places were then reported into a point feature class using ArcMap. This feature class was transformed with the "feature class to shapefile" script into a shapefile. Further on, the shapefile was compressed into a zip file in order to import it into the content folder from the ArcGIS online account.

In the map section of ArcGIS online, the open street map basemap was called and so was the feature class mentioned above. The symbology was then adapted, and the newly created map was saved into the personal content folder. This customised map constitutes the main geographical reference for the story map being created. Four main locations have been listed. Port Harcourt at the beginning of the story, Spiez is the following location where started the trip in Switzerland. Rümliang and Küssnacht are listed as part as the field visits and Spiez once again to conclude the journey.

2.3.3.2 The pictures

The pictures were selected from the visit of UNEP representatives in Nigeria at the beginning of 2019. More were as well selected from accompanying the HYPREP personnel during their journey in Switzerland. These pictures vary from detailed views to plainer views. Some are purely illustrative such as group photos while others are more explanatory such as pictures with activity taking place.

2.3.3.3 Getting started

The story map is created from the "content" folder in the ArcGIS online account. In ArcGIS online, the story maps are considered as web applications. Therefore, in order to create the story map, a new "App" must be selected. Creating from a template has noticeable advantages. There are various templates to choose from and all have a short description making it easy to decide which solution is the best according to needs. Once the template has been chosen it is a matter of following the steps.

2.3.3.4 Editing

The story map template chosen for this example is the "Story Map Shortlist". It is a practical example of relating locations to activities and is ergonomically presented. There is a field for the text and photos and the main screen is occupied by the map or another picture. All can be edited and finding how to modify elements is straight forward. At the top of the window is the "settings" tab, where most of the large features can be modified. It is under that tab that can be found the map view options for instance, among other cosmetic changes.

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The story starts by adding a new page. This new page will necessitate a title, in order to reference it among the others, and the author is immediately asked what the background will be. The options in this template are: Map, Image, Video or Webpage. In this current case, map, images and videos were selected at various occasions. The maps can be from the web, from an organisation registry in ArcGIS online or a custom map created especially for the story map like in this report. When choosing the map, the level of zoom into one region can be selected as custom view.

The next step consists to add text in the appropriate area, but images, videos and links can be added too in the same area. It is a good practice to put in a title at the top of the text/image area. Other types of data can be added such as informative plots, provided they have been saved as image formats (jpeg, png, etc.).

Once editing the page is over, the project must be saved (see finished page in Figure 27). The next step consists in sharing the story map with other users. There are different levels of sharing such as group level and public level.

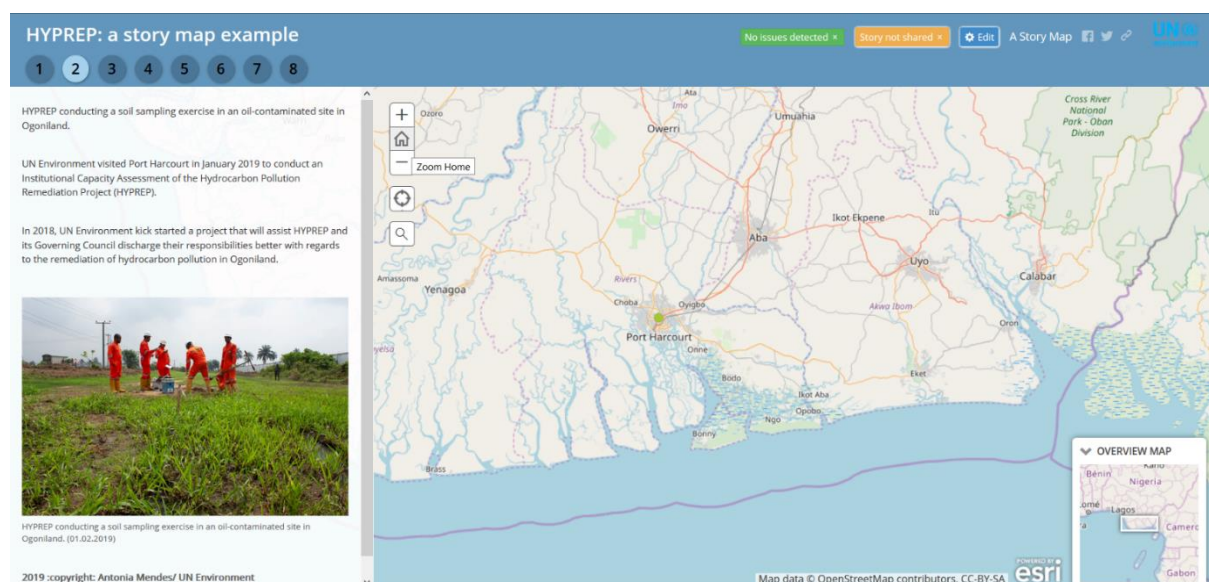


Figure 27: HYPREP story map example. Text and illustrations are situated in the left pane. In the background, the custom-made map to illustrate the different locations of the journey. <https://uneplive.maps.arcgis.com> 2019

2.3.4 Conclusion

Story maps are very useful tools that provide information in a structured and entertaining yet professional manner. The web app templates available on the ArcGIS online platform have proven to be very useful and convenient enabling the author to focus solely on the story to be told or shared.

2.4 General Support

Part of the HYPREP project is to help with general support that might be required by the Nigerian GIS experts working on polluted site remediation in Ogoniland. The latter were trained in Geneva during the summer 2019 and have a good knowledge of GIS based software and methods but sometimes encounter problems that require external help. It is in this scope that part of the internship was dedicated to deliver general technical support.

2.4.1 Email hotline

The HYPREP GIS experts have the opportunity, when problems arise, to liaise with the UNEP/GRID-Geneva office and submit them. The problems are then addressed as best as possible taking into account the distance and the communication challenges. Problems concern the use of ArcMap 10.6 and ArcGIS Online and requests are sent by email and more rarely by skype. Problems aren't easy to diagnose due to the lack of direct observation but then, a couple of solutions are sent trying to cover all the possible issues that might have triggered the problem. This activity occurred two to three times per month.

2.4.2 Dropbox

Part of the GIS concepts is the correct storage of data. In that regard, dropbox accounts were created for each of the three GIS experts in Nigeria working for HYPREP. From their accounts, they can access to a shared folder, specially created, where the GIS and related data (pictures, manuals, contact lists) can be stored and accessed by all who share the folder. The aim of this shared dropbox folder is to educate in the proper structuring of data. The saving method focuses on giving to data, names that are based on locations and dates (Ex: Ogoniland_01.01.2019....). Combined to a tree like structure, data can be easily accessed due to a proper sorting (see Figure 28). Due to the specific names, a simple look through, enables the user to have a good understanding of the data, saving precious time.

A first attempt of uploading pictures was carried. There were a couple of issues which saw the author remove them from the joint dropbox folder. The first issue was the localisation of the pictures in a random folder when a purpose created folder should have been used. The second issue was that pictures were often uploaded twice but in different subfolders and with different names.

The positive elements were the names under which the pictures (locality) were saved and the fact they were accompanied by dates directly printed on the picture. Even altitudes were stamped on some of the pictures.

Upon pointing out the minor mistakes the author acknowledged the errors and pledge to start over. Having observed this with success, the dropbox ownership was transferred to the Nigerian GIS experts.

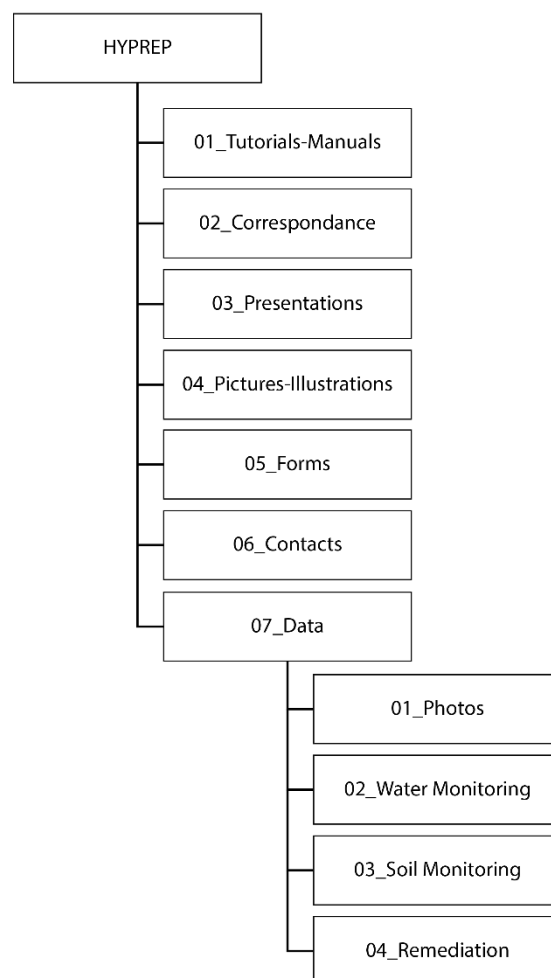


Figure 28: Dropbox folder arrangement

2.5 Geodatabase

The advantages and functionalities of a database are multiple. The primary function being the storage of data in an ordered and described manner, this feature allows the interrogation of the database for research, modification or interrogation purposes. A project based on a database becomes more robust and reliable. It is as well the source of varied, useful and pertinent information provided that it well cared for.

Taking care of a database implies, updating data, deleting irrelevant and adding relevant data. Another very important aspect is the metadata. This data about the data is extremely crucial to validate the information serving a purpose. A result can rely on a robust methodology but if the initial data was acquired in a shady manner, the result is completely irrelevant. Therefore, it is important to maintain a level of quality of the metadata

For the purpose of this project, the objective was to create a geodatabase containing numerous types of data that might be useful and relevant for the GIS personnel within HYPREP. Data present in the geodatabase came mainly from the Ogoniland Environmental Assessment from 2011. This information can be viewed and obtained from the following this link: <https://app.mapx.org/?project=MX-RDI-NEU-3EK-UPI-RE2&language=en>. The rest of the information was found on various websites listed in the annexes and include borders, transport networks, natural features but as well socio-economic datasets. These datasets comprise feature classes, rasters, shapefiles and CSV tables. All have been provided with metadata as best as available although sometimes missing.

2.6 Results and Conclusions

The work carried is part of a multi-phased program. More specifically, the tasks performed are part of phase 2, that has yet to be confirmed. If it were to be confirmed, the two tools and the geodatabase would serve the GIS experts from HYPREP on a daily basis, strengthening their working capabilities. The tools can be used by anybody. It wasn't specifically tailored to work in only on setting. Therefore, even if never used by the GIS experts from HYPREP, the tools can be employed anywhere else if needed.

In the scope of the internship, the HYPREP project provided the opportunity to work with ArcGIS and model builder in order to perform a complex task. Furthermore, the project allowed for some programming skills to be used and developed in order to automate or simplify the use of a script.

3 The Economics for Ecosystems and Biodiversity pilot

This chapter presents the work carried as part in the involvement in the The Economics for Ecosystems and Biodiversity (TEEB) pilot. The goal is to develop a series of dashboards and story maps presenting the work of this organisation of UNEP, which was carried in Tanzania, Bhutan and the Philippines. The first step of the project was to get acquainted with the reports by reviewing thoroughly all three and summarising all the data available into distinct documents. The next step was to elaborate possible dashboards by creating mock-ups and compile the conclusions into a report constituting one of the deliverables in the scope of the project. Furthermore, a report on the processed data was as well written as part of the deliverables agreed for, for the end of the year (2019).

3.1 Introduction

The economics for ecosystems and biodiversity (TEEB) is an organism that aims to show and share the value of nature's resources. This organism relies on economic analysis of ecosystems services in order to characterise them. This in turn enables the best possible interpretation of outcomes in cases of miss-usage of those natural services for instance.

An assessment usually produces results in the form of numbers, should it be statistical or monetary values. It however also produces maps which enable the direct interpretation from a geographic point of view. These maps have a strong demonstration capability that can serve well in a GIS platform such as MapX. The latter geographic information viewer has the resources and power to put data together and enable comparison between data. These comparisons can be done using different views or using tools such as dashboards or story maps. The advantage of such tools is the interactivity of the numbers produced in the reports with the maps created. Both being visualised together thus bringing context to the sometimes, difficult to understand, plots and tables.

It is in this scope that a partnership arose between TEEB and GRID-Geneva in order to see what the outcomes would be and how they could help TEEB further strengthen their communication means.

3.2 Contextualising the project

The first step of the project involved giving it a context. With that in mind, a new project was created in MapX in order to host the future data but as well to assemble a collection of views pertinent to the themes addressed by TEEB. In order to do so, a selection of projects from the latter organisation was reviewed and the main topics extracted. Following this work, existing MapX projects were scanned through in order to select the views pertinent to the previously extracted topics. These views were then all added to the newly created TEEB project and categorised. These categories were in turn sub-categorised as well in order to better reflect the meaning of the data collected and to help with navigation (see Figure 29).

The main topics of the collected views were environment related or with a socio-economic trait. Roughly eighty views were collected and assembled in the project.



Figure 29: Views categories and sub-categories in the TEEB project. <https://app.mapx.org/?project=MX-KTK-1VN-8L7-1NX-OZ3&language=en>

3.3 Dashboard feasibility: Tanzania

The second step of the project pilot is to implement different dashboards in MapX. This tool is excellent to display both written data and geospatial data together. The most basic display would be information that would be localised on a map for instance.

In that scope, the pilot was started on an assessment carried in Tanzania, on a river basin in the south of the country, the Kilombero cluster, and its planned future socio-economic growth program (Southern Agricultural Growth Corridor of Tanzania, SAGCOT). The governmental program was purely to develop the southern region of Tanzania in spite of all environmental potential damages that could incur. The TEEB assessment therefore focused on different scenarios including the planned SAGCOT scenario, interrogating such a development. Some of the scenarios integrated environmental parameters in order to compare with the standard governmental plans. These scenarios were computed using SWAT, CROPWAT and InVEST. These software produced numerous plots and maps that can be seen in the assessment report and potentially used in the scope of this pilot.

Most of the plots covered the evolution of different socio-economic parameters such as population, total land used for agriculture, urban area or ground water use for instance. These plots cover a thirty-year timescale. Two different maps were output from the analysis. The first map is a land use/cover map and the second is a carbon dioxide sequestration map. The most important feature of these two types of maps is the fact that each represents a scenario summarising the status in the year 2030. This is where a dashboard in a GIS viewer can be powerful, because these maps can be compared to each other in a unique interface. The element of comparison is one of the strongest properties in any argumentation. The use of a dashboard enables that comparison.

The different scenarios include a business as usual model (BAU), the SAGCOT development model, both latter models but with a water constraint (WC) and finally a SAGCOT intensive (INT) model. For each scenario a land cover and a CO₂ sequestration map are available as well as the respective plots.

Developing a dashboard for each scenario using relevant plots with an associated map is foreseen. In other words, the aim is to create one dashboard per scenario in order to be able to easily compare them (see Figure 30, full size in annexes). The number of plots in the figure below is two but more can be added. If more plots were to be added, a scroll bar would enable the viewer to see beyond the two first plots. The question of ease of readability and understanding of the data springs however into mind.

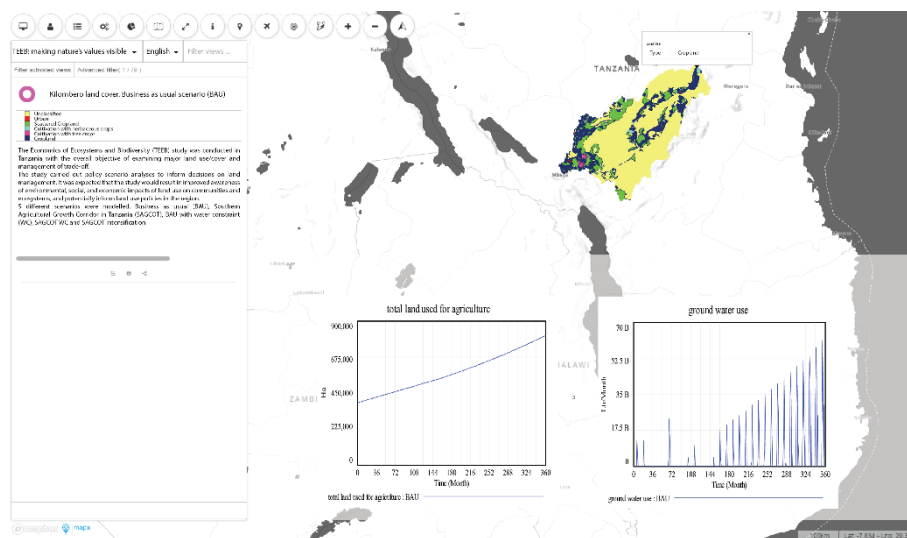


Figure 30: Tanzania BAU scenario dashboard mock-up

Additionally, a “summarising” view can be created with all the maps included in a scenario slider enabling the user to compare land use or CO₂ sequestration maps all together. In the left-hand panel, a slider would enable the user to toggle the maps between scenarios (see Figure 31, full size in annexes).

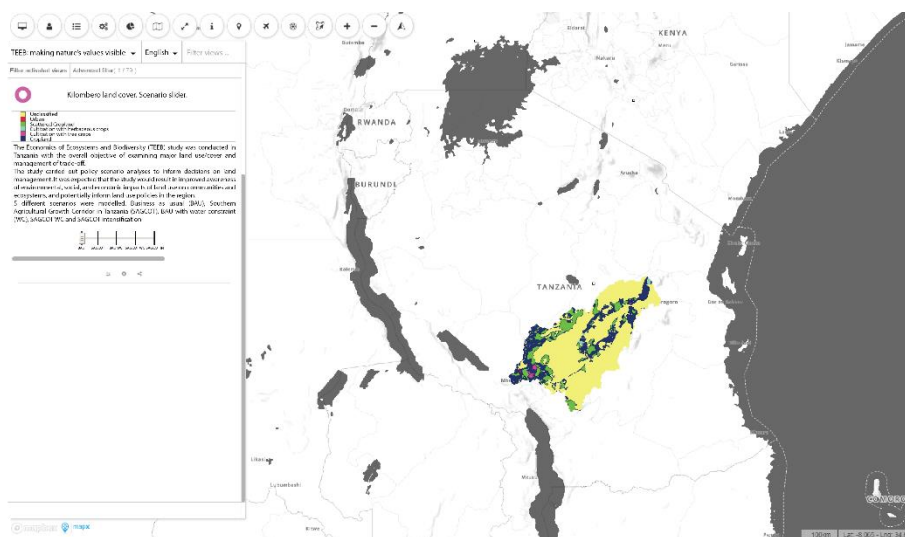


Figure 31: Tanzania Land cover scenario slider mock-up

For two dashboards per scenario (land use and CO₂ sequestration), five scenarios and two summarising sliders, the Tanzanian project would contain 12 views in the TEEB project. They should also be prioritized according to the requirements of the SSFA, which indicates the development of 5-6 dashboards in total.

3.4 Bhutan case study

3.4.1 Introduction

The Royal Government of Bhutan plans on developing its hydropower capacity in the coming years. With funding from the European commission and TEEB’s expertise, an assessment of changes in ecosystem services provisioning under different hydropower diversifications scenarios was carried. The three scenarios included a business as usual model (BAU), a standard hydropower development strategy model and the same latter plan but with mitigation measures, such as reinvestment in reforestation for instance.

The assessment focused on socio-economic trends (desired agriculture, habitat quality, land, tourism arrivals), land use changes and ecosystem services (forest cover, agriculture production, carbon sequestration) and hydropower outputs (hydropower dam capacity, electricity generation and associated revenue).

3.4.2 Dashboards

As indicated above the plots are numerous and belong to many different indicators. Every output is plotted over time, providing insight into the evolution in the future. However, to the contrary of the Tanzanian assessment, no comparison is carried directly between the scenarios in terms of geospatial data (maps) in the report. Plots do have multiple curves for the associated scenarios, but no maps could be used to compare scenarios like in the Tanzanian scenario slider. In the case of the Bhutan study, it would be a time slider between two states (2010 and 2030, according to the data in the report) in time of the same scenario.

The Economics for Ecosystems and Biodiversity pilot

In terms of dashboard, a map in output would be associated with the corresponding plot to form one dashboard. Available printed maps in the annexes of this document are: habitat quality, P load, Nitrogen load, water yield, and lower and upper carbon sequestration, in all cases, from 2010 and 2030. The report doesn't specify which scenario is depicted on the maps. This should be however possible. The report provides the information on which data is available, it is however difficult to precisely determine how many dashboards could be created because the combinations are abundant. Close cooperation with the TEEB team is necessary in order to create the desired dashboards.

According to the data inventory, it could be possible to have a three-dimensional interpretation encompassing time, the type of scenario and a particular thematic (ex: Carbon sequestration, 2010 to 2030, BAU scenario). Every dashboard could implement the use of a time slider while depicting a particular topic under one scenario (see Figure 32, full size in annexes). Additionally, a red plot marker could help the viewer locate the situation in time according to the view toggled in the slider.

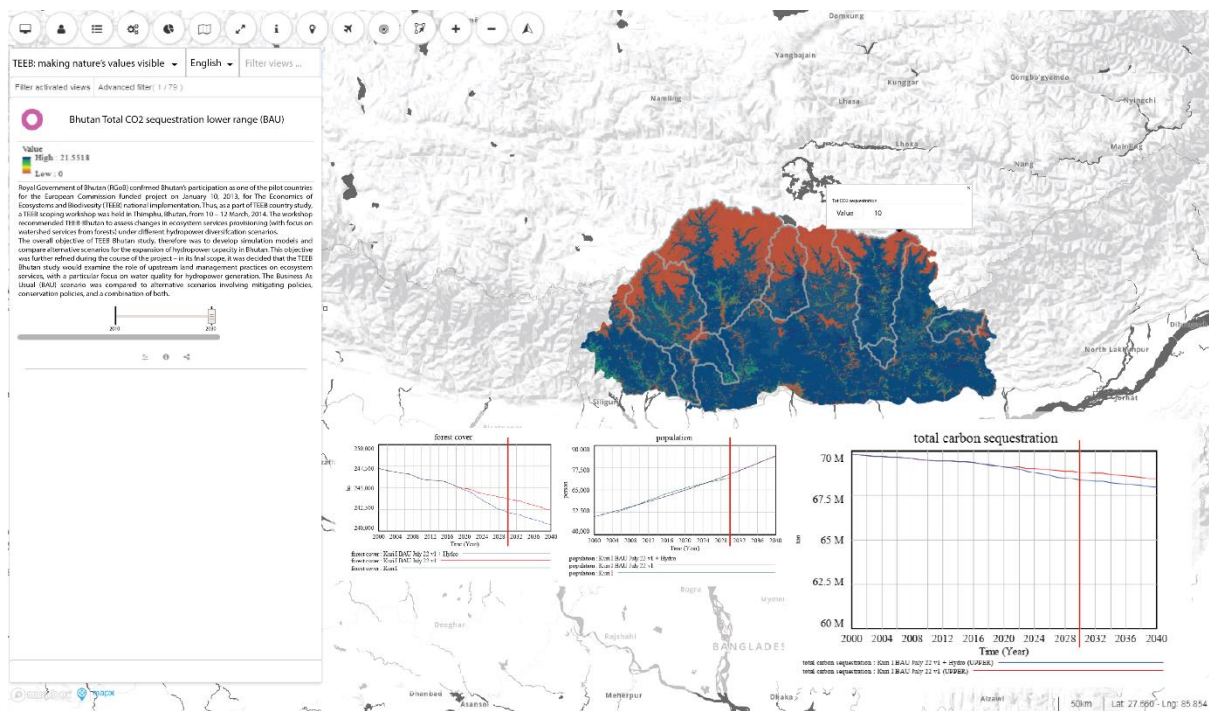


Figure 32: Mock-up of a Bhutan carbon sequestration , business as usual, 2010 to 2030 dashboard with time slider and plot marker

3.5 Philippines case study

3.5.1 Introduction

The Philippines Reclamation Authority (PRA) plans to implement a large reclamation program in the Las Piñas-Parañaque Critical Habitat and Ecotourism Area (LPPCHEA), commonly the Manila Bay, that could be done to the detriment of ecosystems such as mangroves or mudflats but could as well harm ecosystem services vital to local populations impacting fishing, tourist revenues and crucially protection to natural disasters such as storm surges. The area is however declared as a critical habitat and ecotourism area under presidential decree and it is also a Ramsar site since 2013.

Two pathways are analysed where one pathway implements the reclamation plan, and one which does not. In each pathway further two scenarios are followed including or excluding rehabilitation/restoration.

Pathway 1, scenario one is the business as usual model. No reclamation is enforced, no additional budget is sourced and there are only minor site management implementations. No restoration takes place.

In pathway 1, scenario two there are major site management changes through the restoration process as the coastal bay strategy is fully implemented while fully budgeted. Ten-year-old reclamation plan is not enforced.

Pathway 2, scenario 3 includes the full reclamation plan with no rehabilitation of the remaining natural areas.

Pathway 2, scenario 4 includes the full reclamation plan with preservation of a buffer around the LPPCHEA.

3.5.2 Dashboards

Dashboards can be populated with various types of data from social indicators such as fishery production to natural indicators such as mangrove extent or total biomass. More worked data are as well available as plots such as economic data containing flow of net benefit for instance. Plots can as well be computed from the numerous tables, should they contain quantities or monetary values.

No maps are available in terms of end results of the four different scenarios should it be in the report but as well in the data package received. The scenarios can't be compared geospatially but they can be compared numerically with monetary values for instance. Maps are however available and helped in the analysis of the scenarios, planting the background of the various modelling processes. Dashboards containing contextual data such as reclamation extent maps, mangrove distribution maps, are feasible.

An example of a dashboard could include a map of the demersal biomass including the reclamation project and the relative abundance of biomass survey table and the associated plot (see Figure 33, full size in annexes). This is however a status at some point in time and not an end result depiction. These dashboards can help understand the presentation situation but not depict the outcome of the different scenarios.

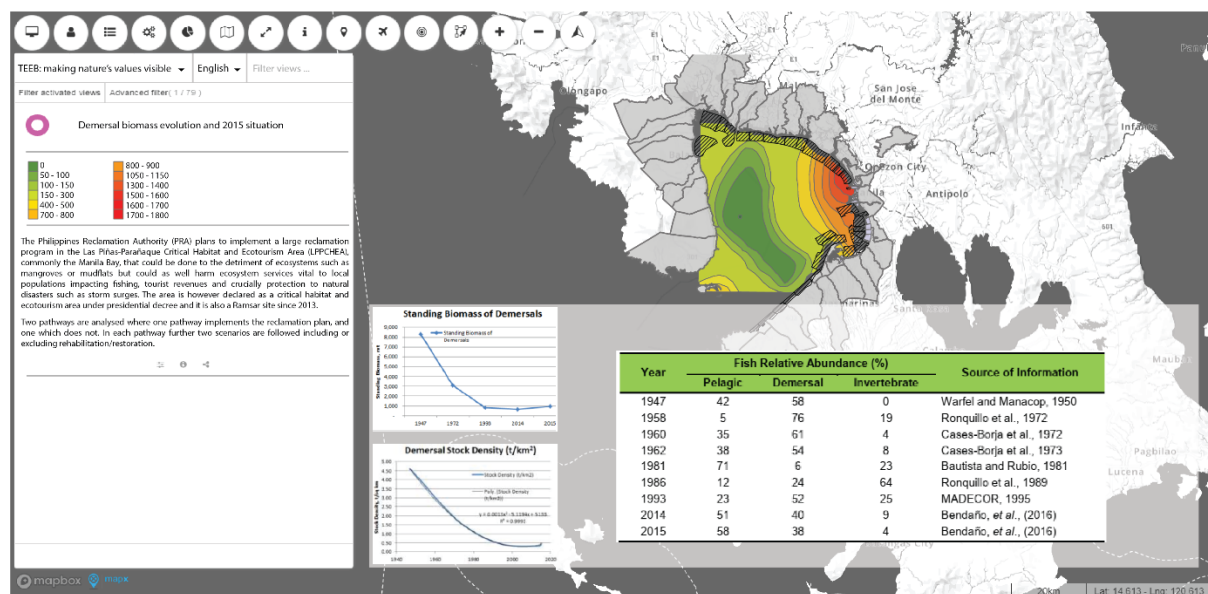


Figure 33: Manila Bay Area, Philippines, context dashboard showing biomass evolution and situation in 2015

A dashboard does not have to have any particular background. The most important information is the end result of the analysis process. A conclusive dashboard could contain a plain map of Manila bay with the resuming numbers in the form of a table (see Figure 34, full size in annexes).

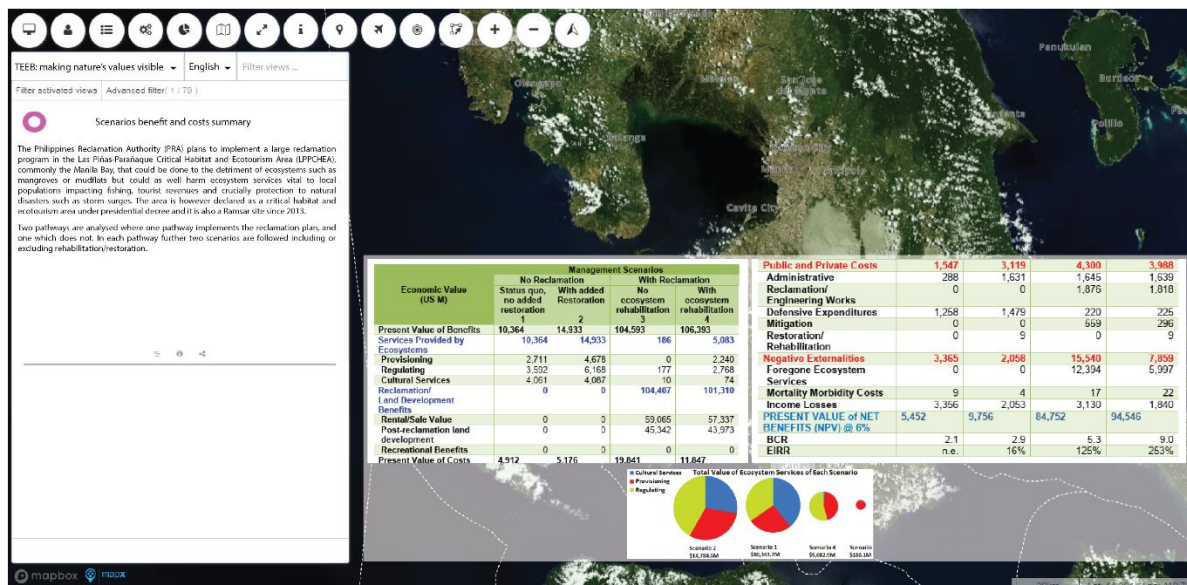


Figure 34: Mock-up of a Manila Bay Area, Philippines scenario summary dashboard with aerial view background

3.6 Conclusions of the feasibility study

Displaying natural capital data or ecosystem services analysis on a GIS-capable platform can be insightful and help convey information to key-role players. The data can be displayed as summarised in this report, as dashboards containing the combination of a map, a plot or a summary table in order to observe a status in time and space. These dashboards can then be put into relation to others through a common criterion such as a fix point in time, a scenario or a particular parameter.

Additionally, views representing different scenarios or different timelines and having a common geospatial extent can be summarised into one single view by using a slider enabling the direct comparison while accompanied by a dashboard. Toggling the different maps (according to timeline, scenario or parameter) would change simultaneously the plots within a single view.

Finally, dashboards can be further included into story maps that can display geographical datasets combined with narrative and multimedia content.

3.7 Outlook and limitations of the dashboard and story map implementations

The feasibility of the dashboards and the sliders is however linked to the availability of the data and their quality. Additionally, metadata is often missing and has to be completed thoroughly whenever possible.

3.8 Data processing

In order to elaborate the dashboards and the story maps, an inventory of all data was carried. This included geospatial data and non-geospatial data. The inventory included plots, tables, maps embedded in PDF files, shapefiles, feature classes and rasters in TIFF and JPEG formats.

Metadata was unfortunately never provided (minimum required: an abstract, a short description of the attribute(s) that is(are) used to display the data, keywords, contact details including contact

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email, periodicity if any, date of release, date of modification, data license, data source). This was as well the case for style files, units, fields from attribute table descriptions. Additionally, the files names were sometimes non-explicit for a third-party user (see Figure 35). The tables supporting the plots were not available preventing any processing.

In the case of the Philippines, rasters happened to be scanned documents which has been saved into a TIFF format. These rasters, which were coarsely georeferenced, were not suitable for geospatial visualisation (see Figure 36).

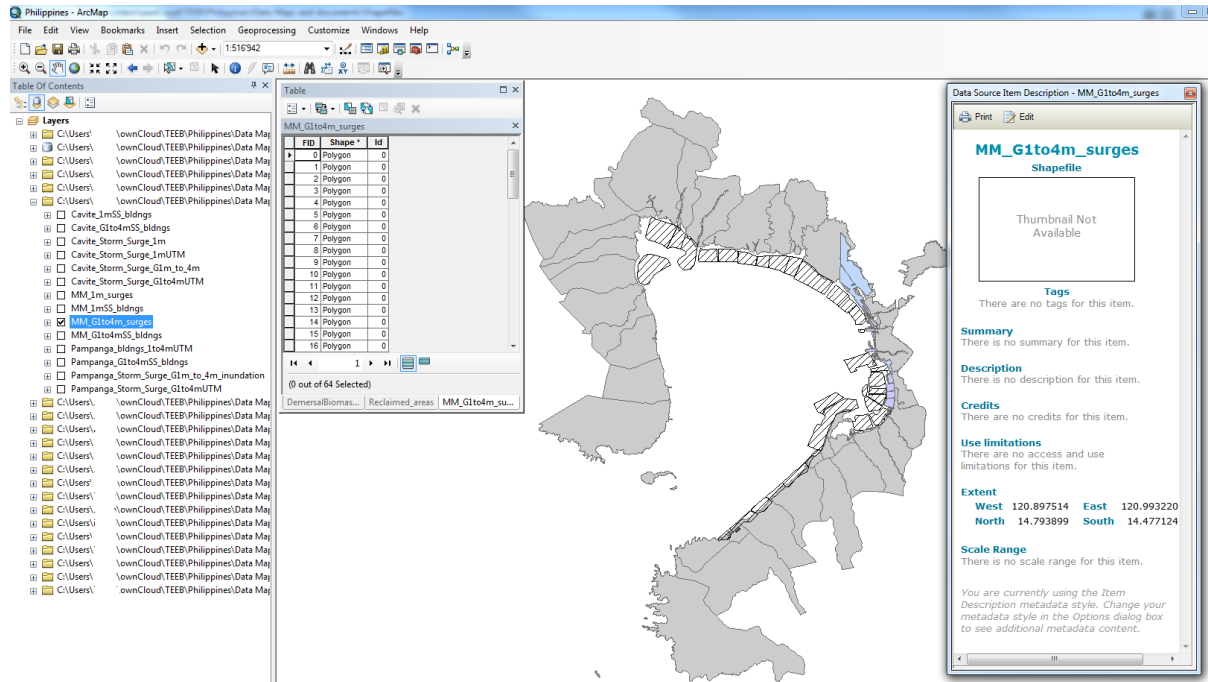


Figure 35: Available data include among others, borders, reclaimed zones, foreseen reclamation zones shapefiles. However, Missing information include metadata, indications to the attribute table fields (description, units), explicit shapefile names.

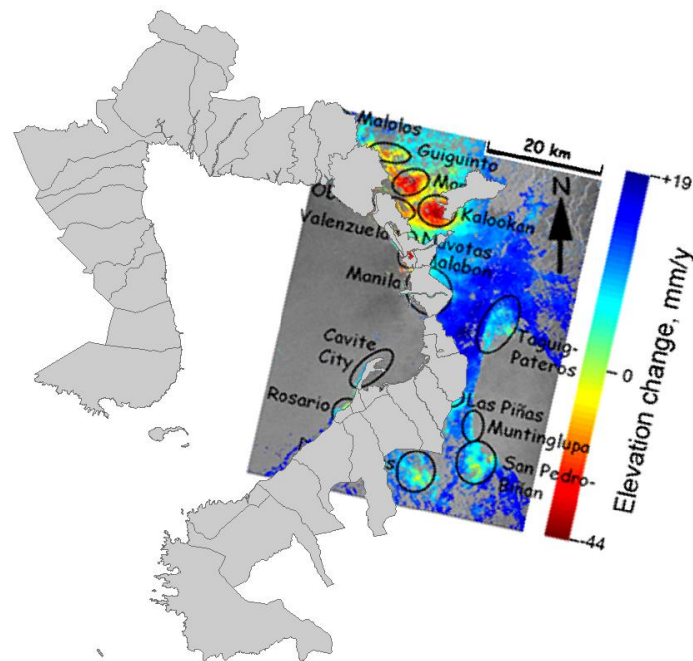


Figure 36: View of Manila Bay area. Combination of vector and raster data. Raster is an original scan in JPEG format and roughly georeferenced.

3.9 Results and Conclusions

The TEEB pilot shows there is great potential for The Economics for Ecosystems and Biodiversity to share about their projects. Dashboards and story maps can positively reinforce the communication capacities of the organisation and help in decision making processes. The possibilities to create the dashboards and story maps are numerous. However, the first challenge involves getting more data of better quality and completeness. The actual data is incomplete and lacks the most important part which are the metadata. The pilot is however on good track to completion.

4 Side projects

Large projects can sometimes suffer from delays which is fully understandable in an international institution. A certain number of side projects were carried in order to be as efficient as possible in times where large projects were lagging.

4.1 MapX lectures

During the course of the internship, teaching sessions were held on the GIS viewing platform of GRID-Geneva. In that matter, the internship included the participation in such lectures in order to help out fellow students with the issues they might have encountered at any stage. The lectures comprised a first hand on MapX (viewing, adding data, interacting, etc). In a second stage story maps were tackled (story board, implementation, capabilities). Training material was as well updated.

4.2 Story map reviews

A thirty-seven-step long story map on socio-economic and environmental data supporting an analysis of the Sahel and west Africa was reviewed. Originally written in English, the story map had been translated into French and necessitated an overlook in order to completely remove any misunderstandings and mistakes that might have still been present in both the English and the French-translated versions. Once this task performed, the implementation of the story map was carried out. In MapX this can be simply done by modifying the JSON code. In that code, the text is written in the French Section of the code. In order to best respect the format, a copy-paste of the original text might be helpful since after that, it is a simple matter of replacement of the original (see Figure 37).

```

1 {
2   "name": "Crop Dominance",
3   "slides": [
4     {
5       "name": "Text",
6       "html": {
7         "en": "<h5>\n  Rain-fed agriculture can only be practiced\nin the region up to the 350
mm rain belt, which\nvaries between 14 and 17 degrees latitude. Sedentary farmers
produce crops including millet, maize, rice and sorghum. <br>Irrigation potential is
widely underdeveloped. Out of the 75.5 million hectares of arable land in West Africa,
only 1.2% is developed for irrigation, and 0.8% is used effectively.\n<br><br> <b>Map
:</b> Crop Dominance (NASA, 2016) & Liveliness Zones - Nomadic and Pastoral Subset
(FEWS Net, 2018)\n</h5>",
8         "fr": "<h5>\n  L'agriculture pluviale ne peut être pratiquée que dans la région jusqu'à
la ceinture de pluie de 350 mm, qui varie entre 14 et 17 degrés de latitude. Les
fermiers sédentaires cultivent le millet, le maïs, le riz et le sorgho. <br>Le
potentiel d'irrigation est largement sous-développé. Sur 75.5 millions d'hectares de
terres arables en Afrique de l'Ouest, seules 1.2% sont équipées pour l'irrigation, et 0
.8% effectivement (ou efficacement) utilisée.\n<br><br> <b>Carte :</b> Cultures
prédominantes (NASA, 2016) & Zones de subsistance de type nomade et/ou pastoral (FEWS
Net, 2018)\n</h5>",
9         "es": "",
10        "ru": "",
11        "zh": "",
12        "de": "",
13        "bn": "",
14        "fa": "",
15        "ps": ""
16      },

```

Figure 37: JSON code for a step of the story map highlighting the different implementation languages

4.3 Story map drafting

A dozen step long story map draft was created in order to synthesise two years of processed data on mercury. GRID-Geneva over the past years have been processing, computing and interpreting data related to the topic of mercury and associated convention (Minamata). The steps of the story map summarised the achieved work on mercury themes from a global to a local scale highlighting the different viewing possibilities.

4.4 Results and conclusions

Side projects are important because they enable to view an activity that occurs on a daily basis in the background and provides vital knowledge that we take for granted. Getting a hand on those projects helps understand the importance they have.

5 Internship recapitulation

GRID-Geneva within the United Nations Environment Program is a very suitable entity in which to carry a GIS related internship. There are plenty enough of projects which all have very large international impacts and where a lot is at stake. Should it be environmental aspects, communication, government policies implementation, etc, the work carried can have a strong incidence.

Projects are varied in their workload, types of activities to be carried or their scope. Nevertheless, they all have in common a geospatial characteristic should it be minor or major in the project.

This internship focused on two main projects, which were HYPREP and TEEB. In the first one, the main focus in terms of GIS was the creation of a simple tool and the optimisation of its python code in order to provide a simple interface for the users. In the latter, GIS projection capabilities were put to the task in order to assess the feasibility of the whole project itself. Thus, the two main activities were programming and planification using previously acquired GIS knowledge.

This knowledge was acquired in class but as well during the internship itself which is its purpose. Learn by doing. Even though highly skilled colleagues are there to provide help in dire need, the primary goal is to get over problems by oneself. And this was achieved.

Therefore, beyond the GIS knowledge developed, strengthened and acquired, other capabilities such as autonomy, time management, auto evaluation were as well maintained.

6 Acknowledgment

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- Frederic Moser for his technical support.
- Antonio Benvenuti for his help and friendly support
- The whole GRID team for providing a welcoming atmosphere agreeable to work in.

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<https://mapcruzin.com>

<http://www.teebweb.org/>

<http://www.fao.org/land-water/databases-and-software/cropwat/en/>

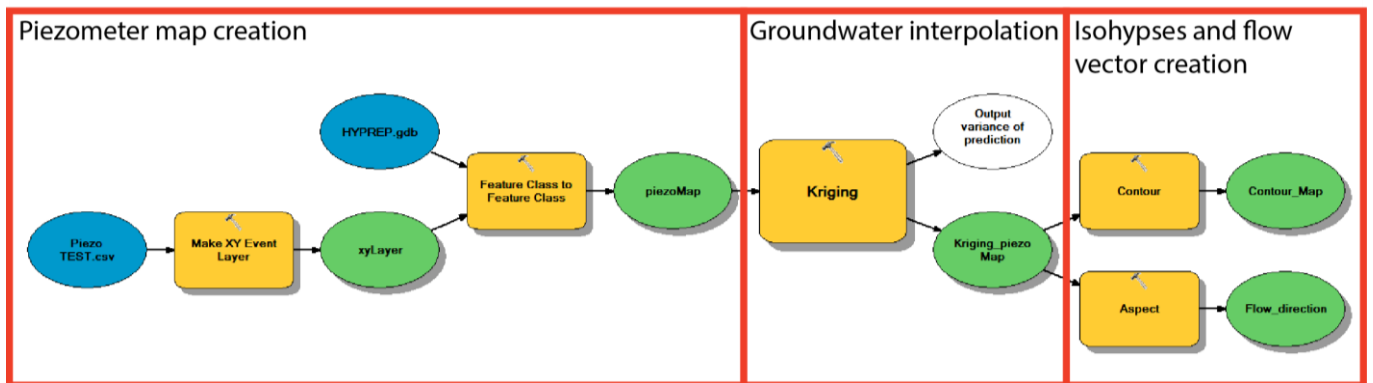
<https://swat.tamu.edu/>

<https://naturalcapitalproject.stanford.edu/software/invest>

<https://www.mapx.org/>

9 Annexes

9.1 Piezometer tool Model builder



9.2 Piezometer tool Python script and compilation success

```

# -*- coding: utf-8 -*-
# -----
# Piezo2.py
# Created on: 2019-10-16 09:23:06.00000
# (generated by ArcGIS/ModelBuilder)
# Description:
# This tool aims at drawing piezometers on a map and computing from their water
# levels the underground water flow. The final product is a collection of layers
# that depict the positions, the water isohypes and the flow direction vector map
# -----

# Import arcpy module
import arcpy

# Overwriting specifications
arcpy.env.overwriteOutput = 1

# Check for the necessary licences
arcpy.CheckOutExtension("3D")
arcpy.CheckOutExtension("spatial")

# External variables that will be acquired via the tool/script in ArcMap or ArcCatalog:
# It is extremely important that the format of the CSV file is respected since the rest of the
# computational process relies on it
Piezo_TEST_csv = arcpy.GetParameterAsText(0)
HYPREP_gdb = arcpy.GetParameterAsText(1)

# Definition of storage and scratch workspace (this has to be adapted to the local environment and can be
# found in ArcMap under "Geoprocessing"-->"Environment settings"-->"Workspace")
arcpy.env.workspace = HYPREP_gdb
arcpy.env.scratchWorkspace = HYPREP_gdb

# code remnants that remain here to test outside ArcMap or ArcCatalog
##Piezo_TEST_csv = "C:\\Users\\intern\\Documents\\Internship\\HYPREP\\Piezo TEST.csv"
##HYPREP_gdb = "C:\\Users\\intern\\Documents\\Internship\\HYPREP\\HYPREP.gdb"

# Below are the local variables created during the computational process.
# This variable is the representation of the piezometers on the map from their coordinates. It is temporary
# and has to be validated through the creation of a feature class.
xyLayer = "xyLayer"

# This variable is the result of the creation of a feature class from the variable above.
piezoMap = HYPREP_gdb + "\\piezoMap"

# This variable is necessary for the Kriging interpolation
Output_variance_of_prediction_raster = ""

# This variable is the result from the Kriging interpolation
Kriging_piezoMap = HYPREP_gdb + "\\Kriging_piezoMap"

# This variable is the result from the Contour tool depicting the isohypes of water levels
Contour_Map = HYPREP_gdb + "\\Contour_Map"

# This variable is the result of the Aspect tool that shows the general underground water flow direction
Flow_direction = HYPREP_gdb + "\\Flow direction"

```

Annexes

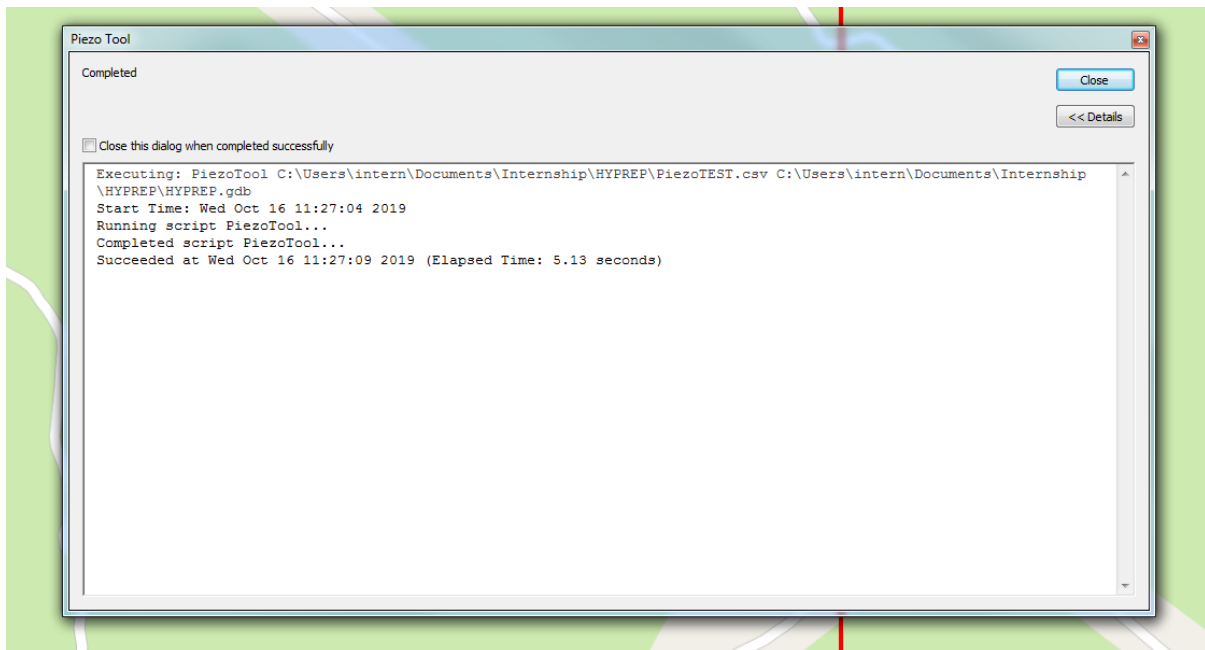
```
# Process: Make XY Event Layer. As stated previously, this process extracts the coordinates of the
piezometers and temporarily draws them on the map.
arcpy.MakeXYEventLayer_management(Piezo_TEST_csv, "X Coordinate", "Y Coordinate", xyLayer,
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwich',
0.0],UNIT['Degree',0.0174532925199433]];-400 -400 10000000000;-100000 10000;-100000 10000;8.98315284119522E-
09;0.001;0.001;IsHighPrecision", "Water level altitude")

# Process: Feature Class to Feature Class. This process creates a definitive representation of the temporary
coordinate representation from the process above.
arcpy.FeatureClassToFeatureClass_conversion(xyLayer, HYPREP_gdb, "piezoMap", "", "Piezo Ident \"Piezo
Ident\" true true false 8000 Text 0 0 ,First,#,xyLayer,Piezo Ident,-1,-1;X_coordinate \"X coordinate\" true
true false 8 Double 0 0 ,First,#,xyLayer,X coordinate,-1,-1;Y_Coordinate \"Y Coordinate\" true true false 8
Double 0 0 ,First,#,xyLayer,Y Coordinate,-1,-1;Piezo_edge altitude \"Piezo edge altitude\" true true false 8
Double 0 0 ,First,#,xyLayer,Piezo edge altitude,-1,-1;Water_level_below_piezo_edge \"Water level below
piezo edge\" true true false 8 Double 0 0 ,First,#,xyLayer,Water level below piezo edge,-1,-
1;Water_level altitude \"Water level altitude\" true true false 8 Double 0 0 ,First,#,xyLayer,Water level
altitude,-1,-1", "")

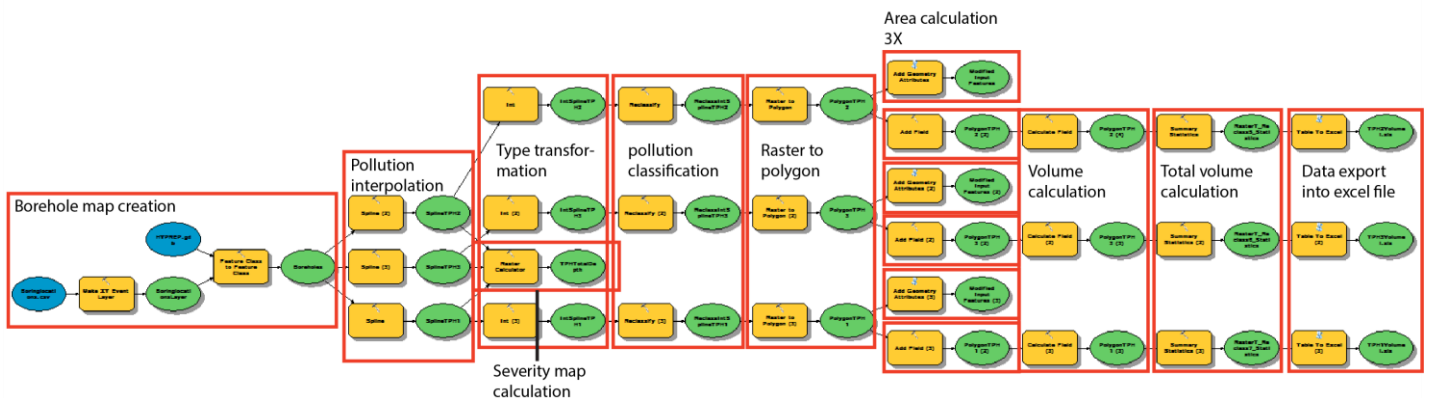
# Process: Kriging. This process interpolates the water levels and flows from the known data (ie. the
piezometer data) in order to reconstruct those levels and flows in areas not supported by any data.
arcpy.Kriging_3d(piezoMap, "Water_level altitude", Kriging_piezoMap, "Spherical 0.000038",
"3.75478959999995E-05", "VARIABLE 12", Output_variance_of_prediction_raster)

# Process: Contour. This process reads the water levels interpolated in the previous step and draws
isohypses. Here it is merely a representation function. The interval is set at 0.1
arcpy.gp.Contour_sa(Kriging_piezoMap, Contour_Map, "0.1", "0", "1", "CONTOUR", "")

# Process: Aspect. This process reads the water levels interpolated during the kriging procedure and draws
flow directions. The method is planar and the units set to meters
arcpy.Aspect_3d(Kriging_piezoMap, Flow direction, "PLANAR", "METER")
```



9.3 Borehole tool Model builder



9.4 Borehole tool Python script and compilation success

```

# -*- coding: utf-8 -*-
#-----
# Boreholes.py
# Created on: 2019-10-17 10:50:11.00000
# (generated by ArcGIS/ModelBuilder)
# Description:
# This tool takes borehole data and shows them on the map. It locates them on a map,
# it interrogates the polluted levels if any and then draws pollution heat maps for every level.
# Additionally it computes rough estimates of volumes based on the thickness of the polluted levels
# in order to have a good understanding of the amount of work ahead during remediation.
# This tool computes as well the addition of all levels together in order to have a severity map
# independent of depth.
#-----

# Import arcpy module
import arcpy

# Overwriting specifications
arcpy.env.overwriteOutput = 1

# Check for the necessary licences
arcpy.CheckOutExtension("3D")
arcpy.CheckOutExtension("spatial")

# External variables that will be acquired via the tool in ArcMap or ArcCatalog:
# It is extremely important that the format of the CSV file is respected since the rest of the
# computational process relies on it
Boringlocations_csv = arcpy.GetParameterAsText(0)
HYPREP2_gdb = arcpy.GetParameterAsText(1)
Volume_excel = arcpy.GetParameterAsText(2)
Thickness_csv = arcpy.GetParameterAsText(3)

# Definition of storage and scratch workspace (this has to be adapted to the local environment and can be
# found in ArcMap under "Geoprocessing"-->"Environment settings"-->"Workspace") but comes with a get
# parameter in the script
arcpy.env.workspace = HYPREP2_gdb
arcpy.env.scratchWorkspace = HYPREP2_gdb

# Local variables that are used during the process
BoringlocationsLayer = "BoringlocationsLayer"
Borehole = HYPREP2_gdb + "\\Borehole"

# Process: Make XY Event Layer. This creates a temporary layer that shows the borehole locations with their
# associated data
arcpy.MakeXYEventLayer_management(Boringlocations_csv, "X coordinate", "Y Coordinate",
BoringlocationsLayer,
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwich',
0.0],UNIT['Degree',0.0174532925199433]];-400 -400 10000000000;-100000 10000;-100000 10000;8.98315284119522E-
09;0.001;0.001;IsHighPrecision", "BH edge altitude")

# Process: Feature Class to Feature Class. This creates a feature class out of the temporary layer created
# at the process above. All processes are followed by a test message to make sure the computation is going on
# well
arcpy.FeatureClassToFeatureClass_conversion(BoringlocationsLayer, HYPREP2_gdb, "Borehole", "",
"Borehole Ident \"Borehole Ident\" true true false 8000 Text 0 0 ,First,#,BoringlocationsLayer,Borehole
Ident,-1,-1;X coordinate \"X coordinate\" true true false 8 Double 0 0 ,First,#,BoringlocationsLayer,X
coordinate,-1,-1;Y Coordinate \"Y Coordinate\" true true false 8 Double 0 0 ,First,#,BoringlocationsLayer,Y

```

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```
Coordinate,-1,-1;BH edge altitude \\"BH edge altitude\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,BH edge altitude,-1,-1;TPH1 \\"TPH1\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH1,-1,-1;TPH2 \\"TPH2\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH2,-1,-1;TPH3 \\"TPH3\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH3,-1,-1;TPH4 \\"TPH4\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH4,-1,-1;TPH5 \\"TPH5\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH5,-1,-1;TPH6 \\"TPH6\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH6,-1,-1;TPH7 \\"TPH7\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH7,-1,-1;TPH8 \\"TPH8\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH8,-1,-1;TPH9 \\"TPH9\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH9,-1,-1;TPH10 \\"TPH10\\" true true false 4 Long 0 0
,First,#,BoringlocationsLayer,TPH10,-1,-1", "")
arcpy.AddMessage("test1")

# Creation of an empty matrix called field_names and list tool to list all the fields starting with "TPH"
field_names = []
fields = arcpy.ListFields(Borehole,"TPH*")

# Use of a cursor that collects all the fields containing "TPH" previously listed and storing them into the
matrix previously created
for field in fields:
    field_names.append(field.name)
#arcpy.AddMessage(field_names)

# Loop going through all the fields containing "TPH" and performing the GIS processes over them
count = 0
while count < len(field_names):
    arcpy.AddMessage(field_names[count])

    # Another cursor going this time going through the rows of each "TPH" field and check the values. If the
Values are <Null> then there the GIS processes are not performed
    Things = arcpy.SearchCursor(Borehole)
    FieldName = field_names[count]
    for Thing in Things:
        Valu = Thing.getValue(FieldName)
        #arcpy.AddMessage(Valu)

    if Valu != None:

        # Process: Spline. This is the interpolation process using the TPH levels recorded in the CSV file to
generate pollution heat maps
        Spline = HYPRE2.gdb + "\\Spline" + str(field_names[count])
        arcpy.Spline_3d(Borehole, field_names[count], Spline, "3.0E-05", "TENSION", "0.1", "10")
        arcpy.AddMessage("test2")

        # Process: Int. This process changes the values from double to integer for the following steps.
        IntSpline = HYPRE2.gdb + "\\IntSpline" + str(field_names[count])
        arcpy.Int_3d(Spline, IntSpline)
        arcpy.AddMessage("test3")

        # Process: Reclassify. This steps reclassify the raster according to a certain number of categories.
Here there are 9 but that can be changed according to desires.
        ReclassIntSpline = HYPRE2.gdb + "\\ReclassIntSpline" + str(field_names[count])
        arcpy.Reclassify_3d(IntSpline, "VALUE", "0 3000 1;3000 5000 2;5000 5500 3;5500 6000 4;6000 6500
5;6500 7000 6;7000 7500 7;7500 8000 8;8000 8500 9", ReclassIntSpline, "DATA")
        arcpy.AddMessage("test4")

        # Process: Raster to Polygon. This step transforms the previous raster into polygons according to the
classification that was established
        Polygon = HYPRE2.gdb + "\\Polygon" + str(field_names[count])
        Modified_Input_Features = Polygon
        arcpy.RasterToPolygon_conversion(ReclassIntSpline, Polygon, "SIMPLIFY", "VALUE", "SINGLE_OUTER_PART",
"")
        arcpy.AddMessage("test5")

        # Process: Add Geometry Attributes. This process adds a geometrical attribute which is the area of
the polygons from the feature class create at the step above
        arcpy.AddGeometryAttributes_management(Polygon, "AREA_GEODESIC", "", "SQUARE_METERS", "")
        arcpy.AddMessage("test6")

        # Process: Add Field. This step adds a field called volume to the table of the feature class just
created.
        arcpy.AddField_management(Polygon, "Volume", "DOUBLE", "", "", "", "", "NULLABLE", "NON_REQUIRED",
"")
        arcpy.AddMessage("test7")

        # Process: Calculate Field. This step calculates the volume of contaminated earth using a depth
parameter added as a table (csv) and the areas calculated above (it is actually an update cursor which is
used).
        Polygon_2 = Polygon
        arcpy.CalculateField_management(Polygon_2, "Volume", "[AREA_GEO] *1", "VB", "")
        arcpy.AddMessage("test8")

        ros = arcpy.SearchCursor(Thickness_csv)
        Fieldname3 = field_names[count]
        for ro in ros:
            Val = ro.getValue(Fieldname3)
```


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```
#arcpy.AddMessage(str(Val) + " is the level thickness of " + field_names[count])

Fieldname2 = "Volume"
with arcpy.da.UpdateCursor(Polygon_2, Fieldname2) as cursor:
    for row in cursor:
        row[0] = row[0] * Val
        cursor.updateRow(row)
        #arcpy.AddMessage(str(row) + " is the volume of respective pollution class")

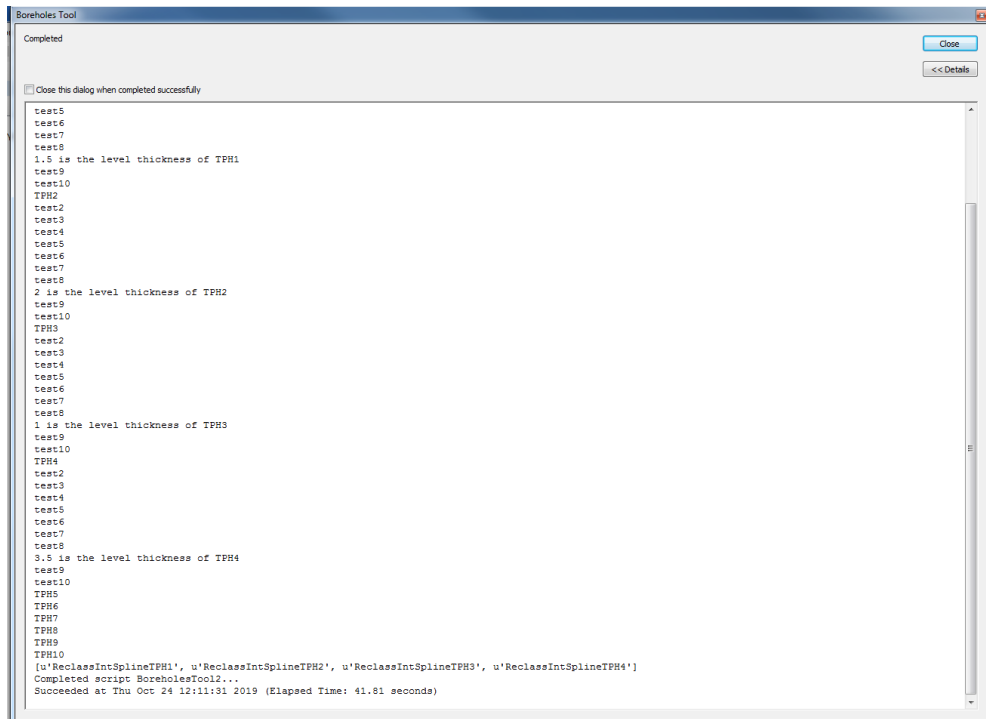
# Process: Summary Statistics. This step summarises all the volumes in the same category of pollution
level
Polygon_3 = Polygon_2
Polygon_statistics = HYPREP2_gdb + "\\Polygon_Statistics" + str(field_names[count])
arcpy.Statistics_analysis(Polygon_3, Polygon_statistics, "Volume SUM", "GRIDCODE")
arcpy.AddMessage("test9")

# Process: Table To Excel. This is an export tool from feature class table in ArcMap to a MS excel
file.
Volume_xls = Volume_excel + "\\" + str(field_names[count]) + "Volume.xls"
arcpy.TableToExcel_conversion(Polygon_statistics, Volume_xls, "NAME", "CODE")
arcpy.AddMessage("test10")

count += 1

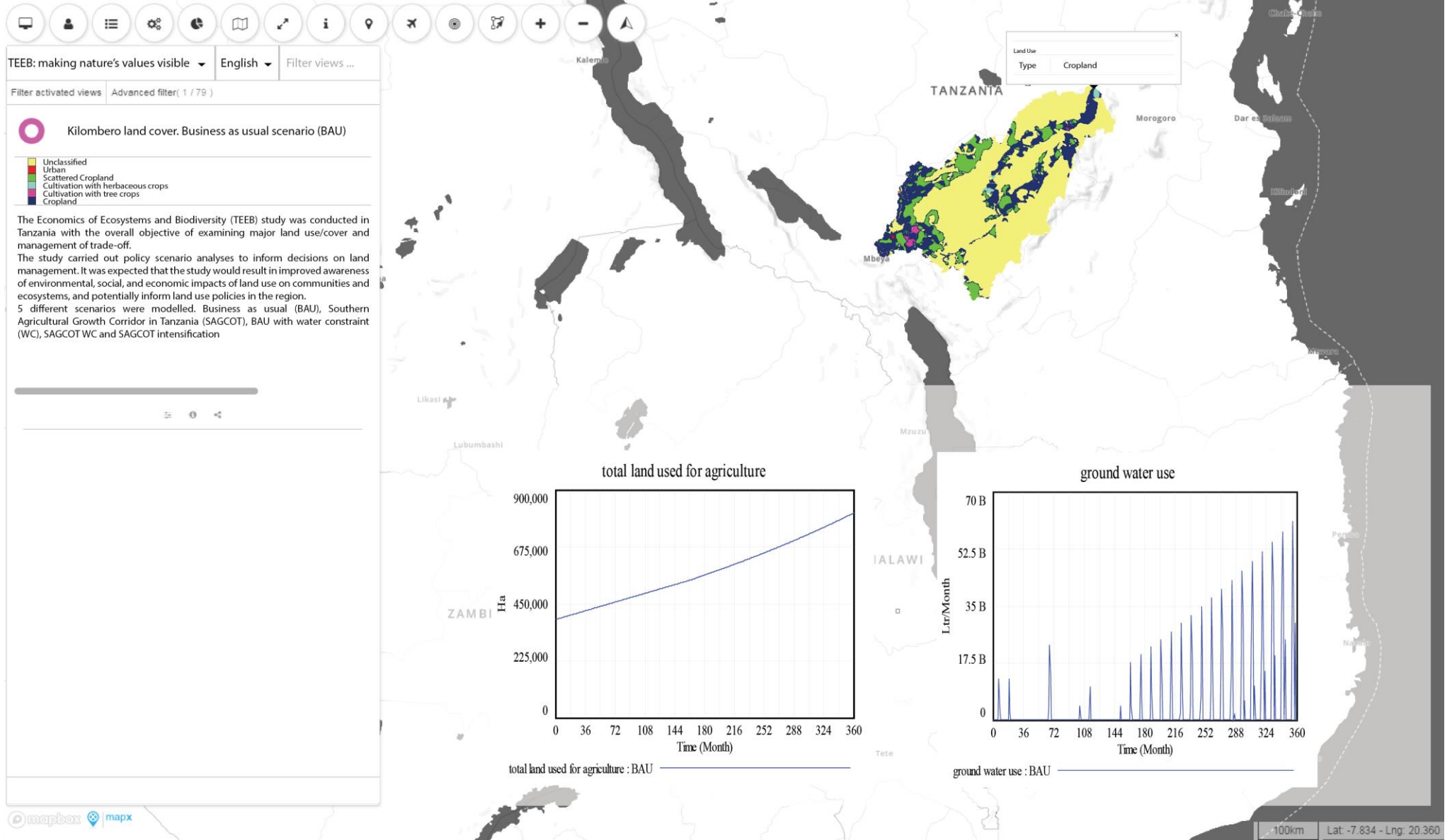
# Process: Raster Calculator
SumTPH = HYPREP2_gdb + "\\SumTPH"
RastList = arcpy.ListRasters("ReclassIntSplineTPH*")
#arcpy.AddMessage(RastList)

arcpy.gp.CellStatistics_sa(RastList, SumTPH, "SUM", "DATA")
```

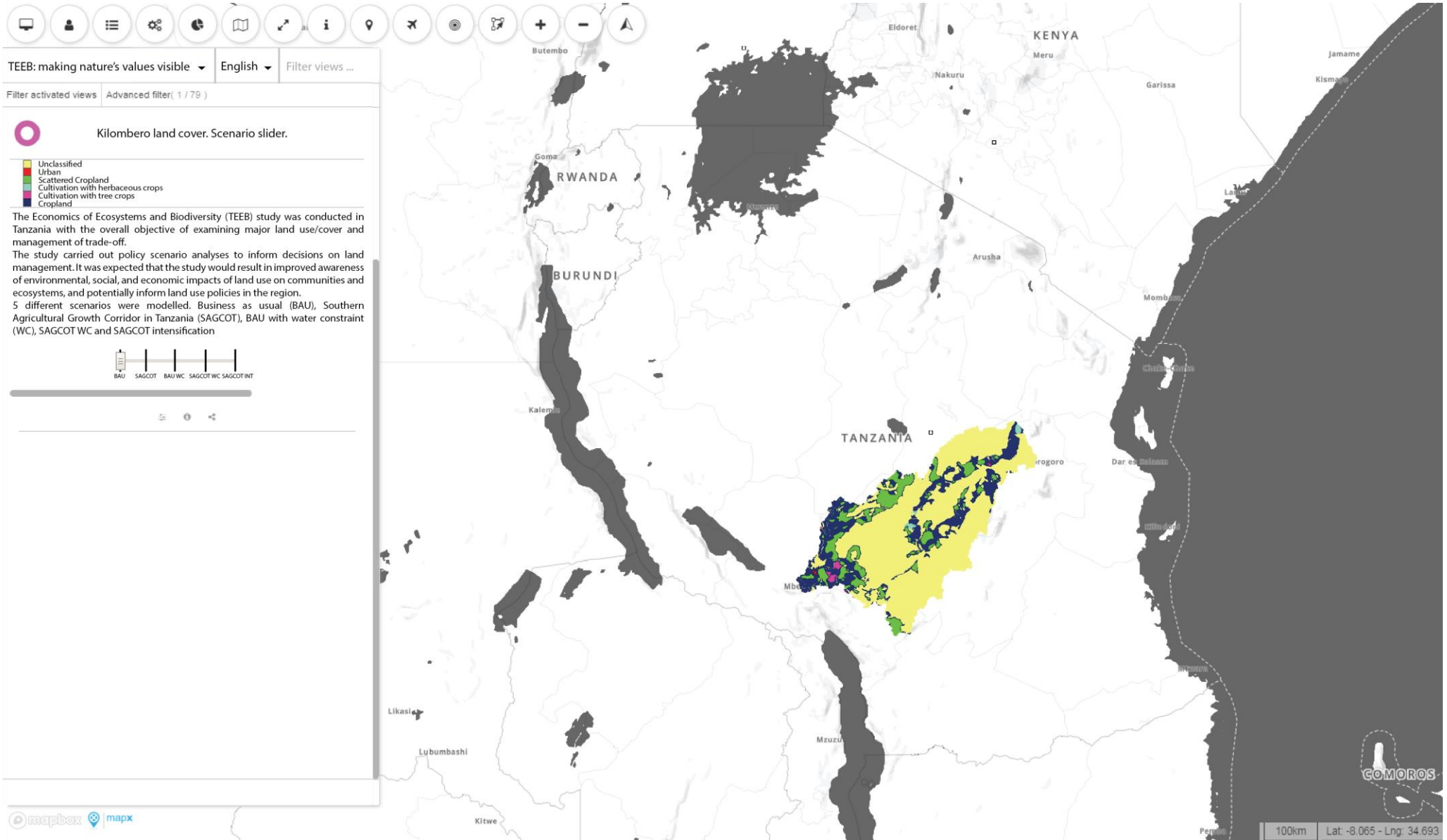


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9.5 Mock-up of a Kilombero basin, Tanzania, BAU scenario dashboard

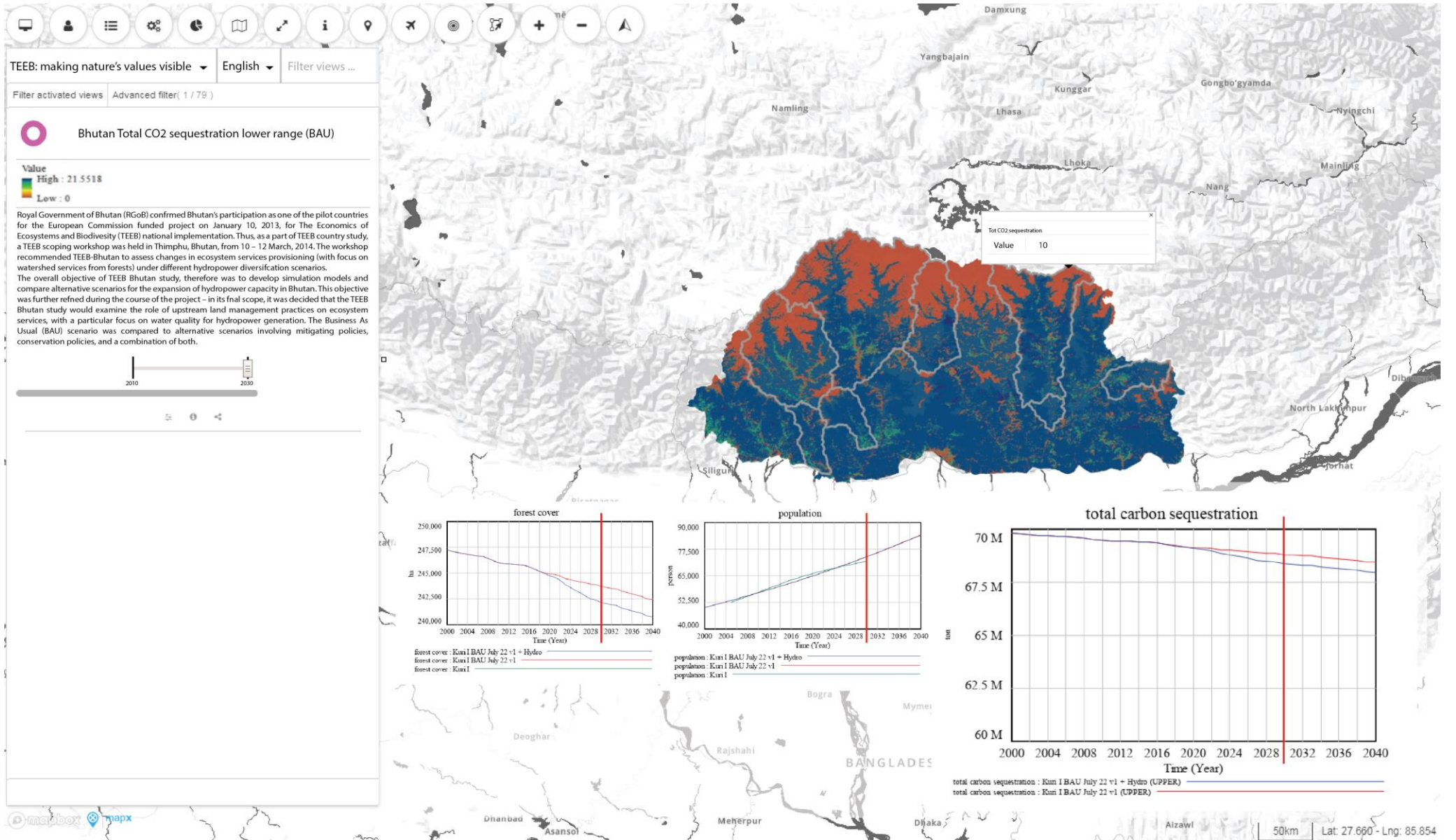


9.6 Mock-up of a Kilombero basin, Tanzania, Land cover scenario slider

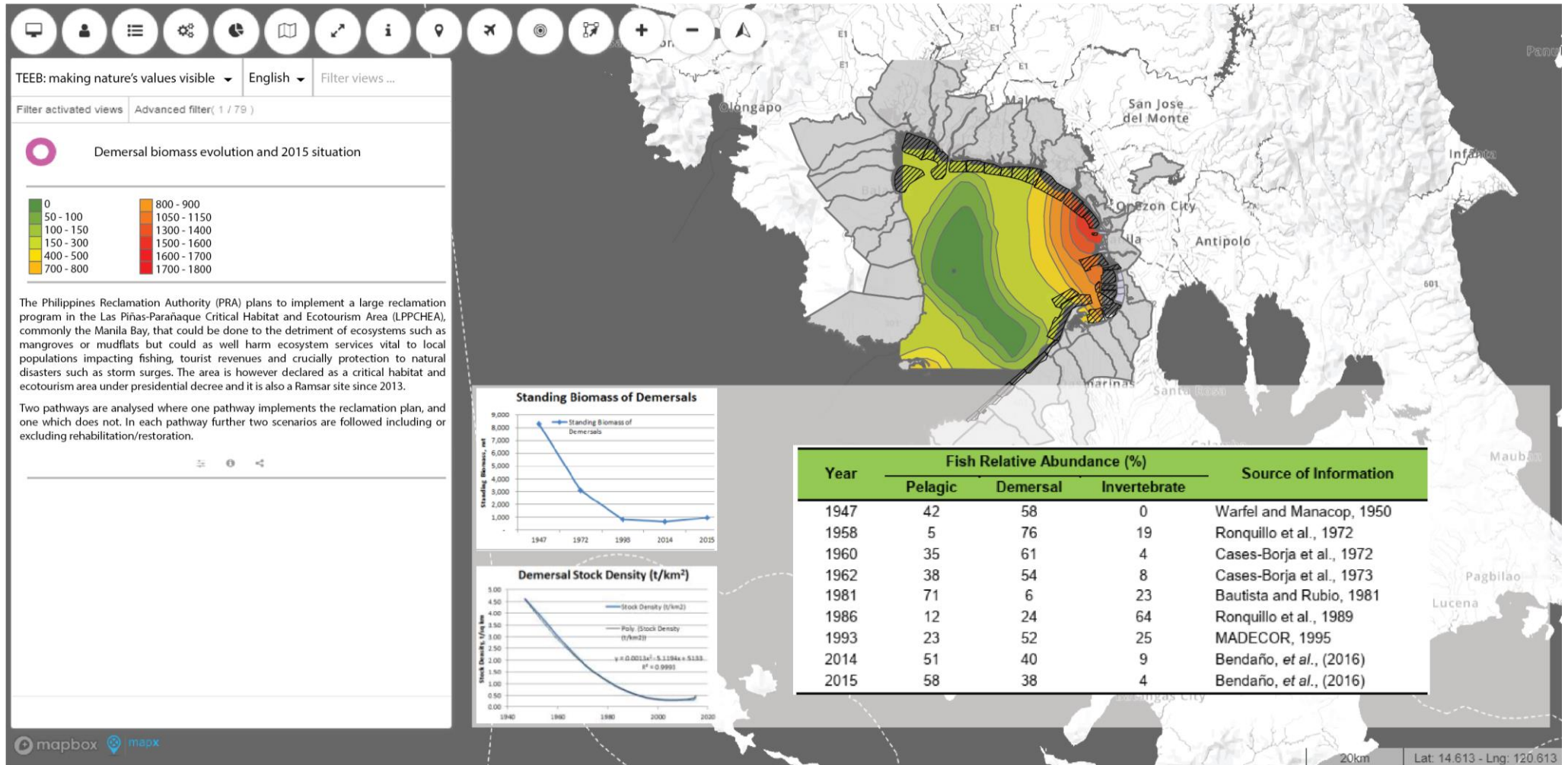


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9.7 Mock-up of a Bhutan carbon sequestration (lower limit) dashboard including time slider



9.8 Mock-up of Manila Bay Area, Philippines, context dashboard



9.9 Mock-up of Manila Bay Area, Philippines, Scenario summary dashboard

TEEB: making nature's values visible | English | Filter views ...

Filter activated views | Advanced filter: (1 / 79)

Scenarios benefit and costs summary

The Philippines Reclamation Authority (PRA) plans to implement a large reclamation program in the Las Piñas-Parañaque Critical Habitat and Ecotourism Area (LPPCHEA), commonly the Manila Bay, that could be done to the detriment of ecosystems such as mangroves or mudflats but could as well harm ecosystem services vital to local populations impacting fishing, tourist revenues and crucially protection to natural disasters such as storm surges. The area is however declared as a critical habitat and ecotourism area under presidential decree and it is also a Ramsar site since 2013.

Two pathways are analysed where one pathway implements the reclamation plan, and one which does not. In each pathway further two scenarios are followed including or excluding rehabilitation/restoration.

Economic Value (US M)	Management Scenarios			
	Status quo, no added restoration 1	With added Restoration 2	No ecosystem rehabilitation 3	With ecosystem rehabilitation 4
Present Value of Benefits	10,364	14,933	104,593	106,393
Services Provided by Ecosystems	10,364	14,933	186	5,083
Provisioning	2,711	4,678	0	2,240
Regulating	3,592	6,168	177	2,768
Cultural Services	4,061	4,087	10	74
Reclamation/Land Development Benefits	0	0	104,407	101,310
Rental/Sale Value	0	0	59,065	57,337
Post-reclamation land development	0	0	45,342	43,973
Recreational Benefits	0	0	0	0
Present Value of Costs	4,912	5,176	19,841	11,847

Public and Private Costs	1,547	3,119	4,300	3,988
Administrative	288	1,631	1,645	1,639
Reclamation/Engineering Works	0	0	1,876	1,818
Defensive Expenditures	1,258	1,479	220	225
Mitigation	0	0	559	296
Restoration/Rehabilitation	0	9	0	9
Negative Externalities	3,365	2,058	15,540	7,859
Foregone Ecosystem Services	0	0	12,394	5,997
Mortality Morbidity Costs	9	4	17	22
Income Losses	3,356	2,053	3,130	1,840
PRESENT VALUE OF NET BENEFITS (NPV) @ 6%	5,452	9,756	84,752	94,546
BCR	2.1	2.9	5.3	9.0
EIRR	n.e.	16%	125%	253%

- Cultural Services
- Provisioning
- Regulating

Total Value of Ecosystem Services of Each Scenario

Scenario 2: \$14,784.6M
Scenario 1: \$10,361.7M
Scenario 4: \$5,082.9M
Scenario: \$186.1M