Participatory approaches and geospatial
modeling for increased resilience to climate change at the watershed level

PWLM Guidebook

Participatory Watershed Land-use Management

環境省 Ministry of the Environment

IGES Institute for Global Environmental Strategies

Participatory Watershed Land-Use Management (PWLM) Guidebook: Participatory approaches and geospatial modeling for increased resilience to climate change at the watershed level

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Concept and objectives of this PWLM Guidebook

This guidebook is intended to provide an overview of how to conduct climate change and land-use change impact assessments, so that the impacts on water, biodiversity, and health can be better understood at the local level. A key aspect of the guidebook is the tutorials provided for conducting climate change/land-use change scenario analysis and impact assessment using free software. The methodology presented (PWLM) and training materials provided can help local governments with their climate change adaptation and land-use planning, and is designed to complement/support countries' official processes. Using these training materials as a basis, more intensive in-person (or online) trainings can also be conducted to provide more specialized or location-specific trainings in priority sites.

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Chapter 1: Introduction

Overview

This guidebook introduces several concepts and methodologies for evaluating and building resilience to climate change and land-use change at a "watershed" (i.e. river basin) scale. Specifically, it presents a framework that we developed, called "Participatory Watershed Land-use Management" (PWLM), which utilizes various participatory approaches and geospatial modeling techniques to quantitatively evaluate the potential impacts of climate change and land-use changes, and to develop suitable countermeasures, at the watershed scale.

The target of the PWLM approach is to help the local governments located within a watershed work together to quantify climate change/ land-use change impacts and develop more resilient development plans, so that future generations can be protected from climate-related hazards and continue enjoying the benefits provided by nature. This guidebook is intended for technical experts (environmental scientists, hydrologists, GIS experts, etc.) and managers/policymakers working at the local level.

Before continuing, we recommend you watch our YouTube video (https://youtu.be/QZ6LCxgaZgg) to get a basic understanding of the PWLM approach.

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Isao Endo

In this chapter, you will:

- Learn how climate change and land-use change can affect communities' resilience at a watershed scale.

- Be introduced to the steps involved in the Participatory Watershed Land-use Management (PWLM) approach, which will be covered in detail in subsequent chapters.

Main concepts

Climate change and land-use change can have significant impacts on people's exposure to climate-related hazards. In many parts of the world, extreme weather events like typhoons and droughts are expected to occur more and more frequently due to global climate change, while large-scale conversion of forests and other natural habitats to urban and agricultural areas is also causing soil erosion and increased river flooding in many places.
Local disaster risks associated with climate change are typically thought of as being related to three factors:

(1) The frequency and level of extremity of the climate-related hazards experienced in the locality;
(2) The level of exposure to these climate-related hazards, e.g. the number of people and properties located in the impacted areas; and
(3) The level of vulnerability of the people/infrastructure/environment in the areas exposed to the climate-related hazards
Figure 1.1 shows how all three factors (i.e. hazards, exposure, and vulnerability) interact to determine disaster risk.

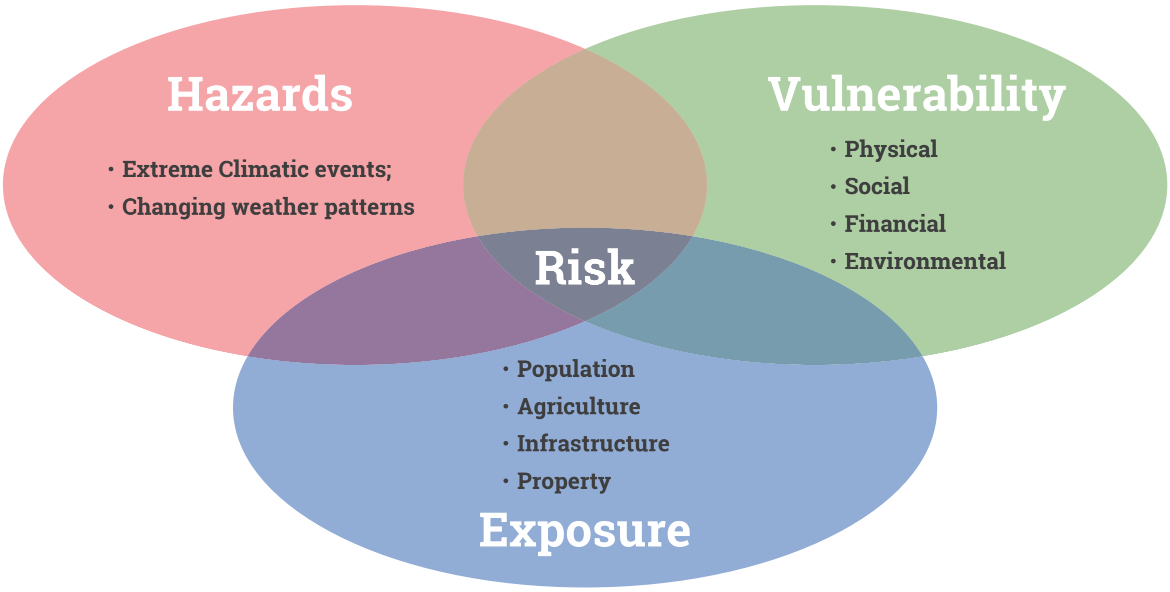


Figure 1.1. Concepts of hazard, exposure, vulnerability, and risk.

Aside from their impacts on disaster risk, climate change and land-use change can have a variety of other local impacts. For example, loss/degradation of natural forests due to changing climate conditions or land-use conversion may result in the loss of biodiversity (due to loss of the habitat of the species living in the forest) and deterioration of water quality (because the forest areas help reduce runoff of contaminants into water bodies), among other things. To help visualize how these types of changes in climate and/or land-use can impact the environment and society, one interesting tool is called the "impact chain" (https://www.pik-potsdam.de/cigrasp-2/ic/ic.html).
The impact chain is basically a graphical representation of how a specific climate or land-use modification (i.e. a "stimulus") is likely to directly and indirectly affect a location of interest. The impact chain can be developed based on scientific models, local knowledge, or other relevant information. One example of an impact chain is shown in Figure 1.2 to demonstrate the approach. From this example in Figure 1.2, we can see that climate change (increasing rainfall and extreme rainfall events), urban land expansion, and agricultural land expansion can have many interlinked direct and indirect impacts. Although the impact chain does not quantify the impacts identified, in cases where more than one stimulus is found to lead to the same impact, we can understand that this impact is likely significant, so efforts should be made to mitigate the problem.

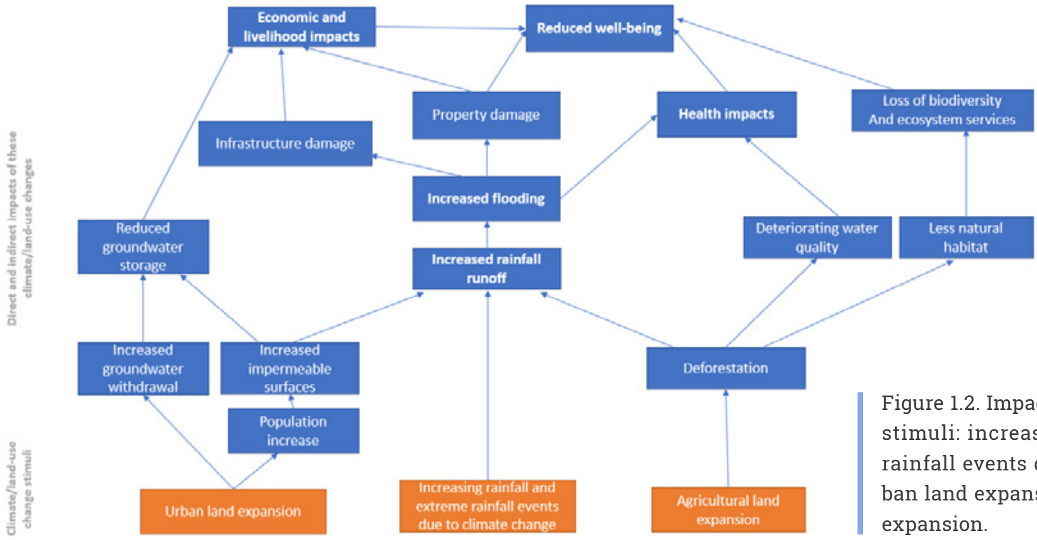
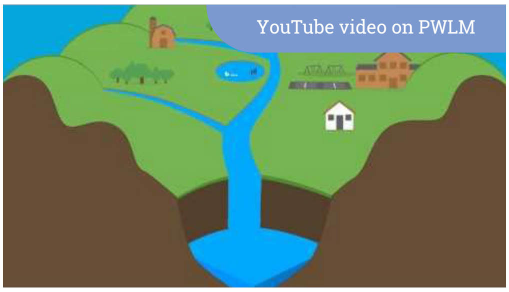


Figure 1.2. Impact chain considering three stimuli: increasing rainfall and extreme rainfall events due to climate change, urban land expansion, and agricultural land expansion.

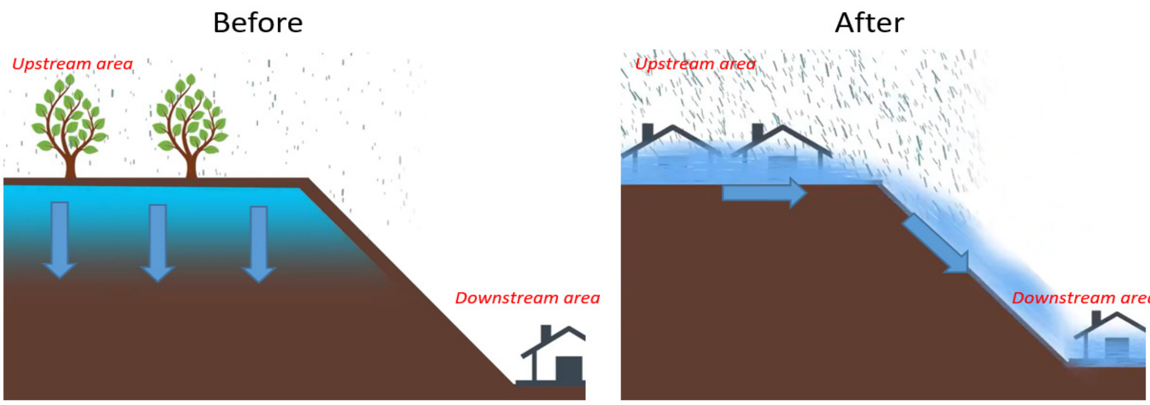
Why is a watershed scale important?

Water-related impacts of climate change and land-use change, including increased flooding, water quality degradation, and drought, are typically experienced at a "watershed" scale, i.e. a river basin or sub-basin scale (Watch Video 1.1. for a detailed explanation of what watersheds are). Changes to the land conditions and/or the climate in upstream areas of a watershed can have dramatic impacts on the population living in the lower elevation downstream areas (see Figure 1.3 for an example). On the other hand, local climate change and land-use plans are typically formulated at the city or town level rather than a watershed level. This can lead to a disconnect between the local plans and the actual climate change/land-use change hazards within a watershed. For example, a city located in the higher elevation upstream part of a watershed may not experience flooding or poor river water quality, but if they do not take it into account, their land-use decisions – e.g. their decision to convert forested lands to impervious urban areas – may unwittingly lead to increased flooding (due to higher rainfall runoff (Figure 1.1) or lower water quality (due to waste discharge from urban areas) in the downstream cities located within the same watershed. Thus, coordinated land-use planning efforts at a watershed level are essential for ensuring resilience to climate change and land-use change.



Video 1.1. What is a watershed (https://youtu.be/QOrVotzBNto)? Source: Battle River Watershed.

Figure 1.3. How climate change and land-use change in the upstream area of a watershed can lead to negative impacts downstream. In this example, increased rainfall (due to climate change) and the conversion of forest to residential land-use leads to higher rainfall-runoff and more flooding downstream.



Participatory Watershed Land-use Management (PWLM) approach

To estimate how climate change and land-use change will affect a watershed, planners and policymakers first need to have an understanding of how the climate and the land-use are likely to change in the future (e.g. over the next 10, 20, or 50 years). Once future climate and land-use scenarios are identified, they can serve as input data for different types of computer simulation models to estimate the impacts of these changes, e.g. on flood hazard, water quality, or biodiversity. The "Participatory Watershed Land-use Management" (PWLM) approach presented in this guidebook is intended to help with this process. The PWLM approach can help complement qualitative approaches like the impact chain (Figure 1.2) by helping to quantify the potential impacts of future climate change and/or land-use change.

In the PWLM approach, future climate and land-use scenarios are generated, the impacts of these changes are estimated using free software/computer models, local governments identify countermeasures to reduce these impacts, and finally the local governments adopt these countermeasures in local plans and policies to increase their resilience to climate change. If some of the identified countermeasures require external funding from national or international sources to implement (e.g. costly infrastructure like artificial wetlands or stormwater retention ponds), they can be used as a basis to develop proposals for climate change adaptation funding from sources like the Green Climate Fund (https://www.greenclimate.fund/). We hope that by using the PWLM approach, local governments and other stakeholders can better understand the potential impacts of climate change and land-use change at the watershed scale, so that more effective policies, plans, and infrastructure can be put in place.

The PWLM approach utilizes a combination of participatory processes and geospatial modeling techniques for this impact assessment and policy development, and consists of four main steps:

1. **Scenario development:** Future scenarios of land-use change and climate change are identified ;
2. **Impact assessment:** Impacts of the future land-use change/climate change scenario(s) are analyzed using different computer models and software;
3. **Countermeasure identification:** Local governments within the watershed identify countermeasures based on the risk assessments, and try to agree upon some priority countermeasures relevant at the watershed scale;
4. **Climate resilient land-use planning and implementation:** Local governments use the identified countermeasures to improve their land-use plans, and for development of climate change adaptation actions and policies. The identified countermeasures can also be used to develop project proposals for domestic or international sources of climate change adaptation funding (e.g. through the Green Climate Fund: https://www.greenclimate.fund/).

Figure 1.2 provides an overview of these four steps, and the processes and software/tools required for each step. All of these processes are described in more detail in the subsequent chapters, and you will learn how to apply them yourselves through a series of hands-on tutorials.

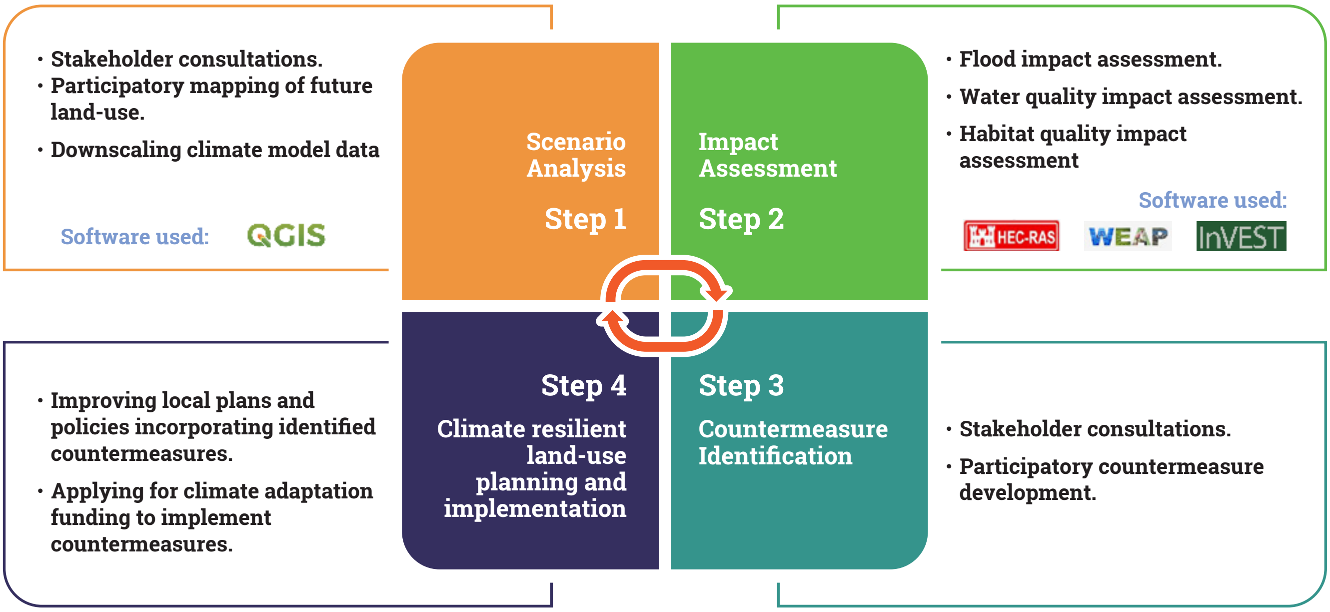


Figure 1.2. Four steps of the PWLM approach, and the different processes and software/tools required in each step.

Step 1: Scenario Development (covered in Chapters 2 and 3)

In the first step of PWLM, future scenarios of land-use change and climate change are developed through participatory mapping (for land-use scenarios) and downscaling of climate model projections (for climate change scenarios).

Land-use scenario development

To understand the likely future land-use changes of a watershed, a participatory mapping approach is used. For this, a stakeholder consultation workshop should be organized, wherein representatives from each local government within a watershed share their land-use and development plans. A map of the future land-use is created through a participatory mapping activity. Local government officials sketch their planned future land-use conversions (e.g. based on their land-use plan, or their knowledge of planned land acquisitions/development) onto a printed map using markers and tracing paper (see Figure 1.3 for some examples). Each local government then presents its future land-use plans to the other local governments in the watershed, so that all have a better understanding of the future land-use conditions of the watershed. Later, the sketched maps are digitized and georeferenced using the free Geographic Information Systems (GIS) software "QGIS". Chapter 2 of this guidebook provides a step-by-step tutorial on how to perform this land-use scenario development.

Climate change scenario development

To understand the future climate changes of a watershed, projections from General Circulation Models (GCMs, a.k.a. Global Climate Models) or Regional Circulation Models (RCMs, a.k.a. Regional Climate Models) are used. GCMs/RCMs are computer models of the future climate, assuming different levels of future greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) has estimated these future levels of emissions under different socioeconomic scenarios known as Relative Concentration Pathways (RCPs). Due to the high level of uncertainty of these future climate change estimates, multiple scenarios should be used to show a range of possible futures. For higher accuracy, the climate model data should also be downscaled and bias-corrected using local climate observations. Chapter 3 of this guidebook covers the basics of GCMs, how to acquire the GCM data, and how to visualize it in QGIS software.

Figure 1.3. Participatory future land-use mapping activity.

Main outputs of Step 1	Software used in Step 1
1. Current land-use map	QGIS: https://www.qgis.org/en/site/
2. Future land-use map	
3. Downscaled climate data (current and future daily/monthly data)	

Step 2: Impact Assessment (Chapters 4, 5, and 6)

In the second step of PWLM, impact assessment, computer modeling software is used to estimate various impacts of the future land-use and climate changes. For the PWLM approach to be open to as many as possible, in this guidebook we have demonstrated how to conduct all of the impact assessments using freely available GIS and modeling software.

Chapter 4 of this guidebook shows you how to perform river water quality impact assessment using the Water Environment and Planning (WEAP) software, using data from a case study site in the Philippines. Chapter 5 shows you how to perform flood hazard impact assessment using three software packages: QGIS, HEC-HMS, and HEC-RAS. Chapter 6 shows you how to perform habitat quality impact assessment using the InVEST software package.

Main outputs of Step 2	Software used in Step 2
Water quality parameters (current and future) Flood hazard maps (current and future) Habitat quality maps (current and future)	QGIS: https://www.qgis.org/en/site/ HEC-HMS: https://www.hec.usace.army.mil/software/hec-hms/ HEC-RAS: https://www.hec.usace.army.mil/software/hec-ras/ Water Evaluation and Planning (WEAP): https://www.weap21.org/ InVEST: https://naturalcapitalproject.stanford.edu/software/invest

Step 3: Countermeasure Identification (Chapter 7)

In the third step of PWLM, countermeasures to reduce the negative impacts of future land-use changes and climate change are identified using a participatory process. For this, the results of the impact assessments from Step 2 are presented to all of the local governments within the watershed, and the local government officials are asked to think of potential countermeasures and write them down (e.g. using markers and adhesive notecards, as shown in Figure 1.4). Each local government presents their identified countermeasures, and finally, some common/priority countermeasures are discussed and identified for the watershed as a whole.

Figure 1.3. Stakeholder consultations to develop countermeasures for reducing the impacts of future land-use changes and climate change.

Main outputs of Step 3	Software used in Step 3
List of countermeasures identified by each local government in the watershed List of priority countermeasures for watershed as a whole	No specific software needed

Step 4: Climate resilient land-use planning and implementation (Chapter 7)

In the final step of PWLM, the priority countermeasures identified from Step 3 are used as a basis for developing more climate resilient land-use plans and other policies, as well as for implementing climate change adaptation actions and infrastructure. This is probably the most important step of PWLM, as the goal of this step is to translate the scientific information generated through PWLM into concrete actions.

Some countermeasures identified through PWLM may be possible for local governments to implement on their own (e.g. changing zoning regulations or building codes), while some measures may be too costly for the local governments to implement without external aid. In case external aid is necessary, the identified countermeasures can be proposed as projects for funding by the Green Climate Fund or other national/international climate adaptation funds. Examples of the types of adaptation projects funded by the Green Climate Fund can be found at https://www.greenclimate.fund/projects?f[]=field_theme:235. The Green Climate Fund and other types of adaptation funds typically require a climate change impact assessment to be conducted prior to applying for project funding (to justify why the funds are needed, and to estimate the benefits of the proposed project). The impact assessments from step 2 of PWLM provide the basis for this assessment.

In Chapter 6 of this guidebook, we show some specific examples of the types of actions that could be taken in step 4 of PWLM, based on the results of a case study conducted in the Philippines.

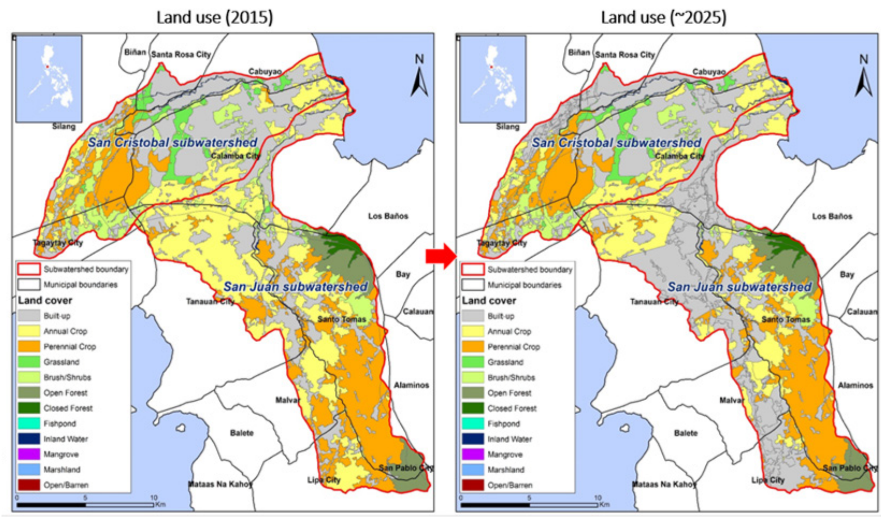
Main outputs of Step 4	Software used in Step 4
1. More climate resilient local policies and plans	No specific software needed
2. Project proposals for climate change adaptation-related funds (to help implement any identified countermeasures that require external funding)	

References

Endo, I., Magcale-Macandog, D. B., Kojima, S., Johnson, B. A., Bragais, M. A., Macandog, P. B. M., & Scheyvens, H. (2017). Participatory land-use approach for integrating climate change adaptation and mitigation into basin-scale local planning. Sustainable cities and society, 35, 47-56.

Kumar, P., Johnson, B. A., Dasgupta, R., Avtar, R., Chakraborty, S., Kawai, M., & Magcale-Macandog, D. B. (2020). Participatory approach for more robust water resource management: Case study of the Santa Rosa sub-watershed of the Philippines. Water, 12(4), 1172.

Chapter 2: Land-use scenario analysis



Brian A. Johnson

Overview of this chapter

Land-use changes can have a significant impact on the biodiversity, water quality, and damage caused by extreme weather events in a watershed. This chapter gives an overview of the impacts of land-use changes, and demonstrates how to perform land-use change scenario analysis. In the chapter, you will learn how to create your own maps of the current and future land-use of a study site using free Geographic Information Systems (GIS) software. This represents the land-use change scenario development component of PWLM Step 1 ("Scenario Analysis"). These maps will serve as the basis for conducting land-use change impact assessments in PWLM Step 2 ("Impact Assessment"), which are explained in Chapters 4-5.

After completing the chapter, you will be able to:

- Perform basic GIS operations in QGIS software (https://qgis.org/en/site/);
- Generate your own land-use maps showing the current and future (planned) land-use.

Main concepts

As introduced in Chapter 1, land-use is a major factor that affects a community's resilience to climate change and climate-related hazards. Conserving and restoring forests, wetlands, and other natural ecosystems can reduce the cause of climate change (CO_2 emissions) as well as the potential impacts like increased flooding and landslides (by minimizing surface runoff and soil erosion). In contrast, converting natural ecosystems or other highly-vegetated areas into urban or intensive agricultural areas can have the opposite effect, resulting in the release of CO_2 emissions from deforestation/forest degradation as well as increased climate-related hazards like floods and landslides (due to increased runoff and erosion). This influence of land-use on stormwater runoff can be clearly seen by looking at the rainfall-runoff coefficients (called "curve numbers" (Soil Conservation Service, 1986)) of different land-use types, developed by the U.S. Soil Conservation Service (see Table 2.1.).

Aside from flooding, land-use change can also have a major impact on the water quality and biodiversity of a watershed, among other things. As one example, when informal or formal settlements are constructed nearby a river bank (as in Figure 2.1.), there is often a deterioration of the river water quality due to the discharge of household wastes into the rivers. As another example, when a natural area near a river bank is converted to agricultural use, there is often increased soil erosion and pollution from fertilizers and pesticides. In both of these examples, the increased pollution from these land-use changes will negatively affect the river water quality (e.g. for drinking, bathing, or irrigation), and may also affect the animals and plants living in the river.

Figure 2.1. Informal settlement built along a river bank near Manila, Philippines.

Land-use / land-cover		"Curve Number" (i.e. rainfall-runoff coefficient) for hydrologic soil groups A-D			
		A	B	C	D
Impervious areas	Paved parking lots, roofs, driveways, etc.	98	98	98	98
Open spaces (parks, golf courses, cemeteries, etc.)	Poor condition (grass cover < 50%)	68	79	86	89
	Fair condition (grass cover 50 to 75%)	49	69	79	84
	Good condition (grass cover > 75%)	39	61	74	80
Row crops	Straight row (SR)	67	78	85	89
	Contoured (C)	65	75	85	86
Fallow	Bare soil	77	86	91	94
	Crop residue cover (CR)	74	83	88	90
Woods/grass combination (Orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Impervious areas	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77

Curve Number value	0-50	50-70	70-90	90+

Table 2.1. Soil conservation service runoff Curve Numbers (CNs) of different land-use types, taking into account the soil type (hydrologic soil groups). Higher CN values indicate more rainfall runoff. Adapted from (Soil Conservation Service, 1986).

Of course, many other factors must be considered for land-use planning, such as demand for urban, agricultural, and recreational land to meet the needs of growing populations and economies. In this chapter, we try to provide you with training in some of the tools/software that can help to better understand and manage the potential impacts of future land-use changes. The first step of this land-use change impact assessment process is to identify or create the needed land-use maps; i.e. (i) a map of the current land-use, and (ii) a map of the planned (or potential) land-use for a desired date in the future. The quality and quantity of available land-use data vary significantly from one location to another, so identifying the appropriate land-use map(s) is not always a simple process. If an accurate and up-to-date local land-use map is already available for your city/town (e.g. a land-use map produced by/regularly updated by your local government), this will probably be the best data to use for an impact assessment. If a local land-use map is not available, you can check online for other existing global-, regional-, or national-level land-use maps to determine if they meet the level of detail (e.g. high enough spatial resolution, and a sufficient number of land-use classes mapped) and accuracy that you require. Finally, in case you need a more accurate/up-to-date/detailed land-use map than what is available, you can always create your own by carefully digitizing land-use polygons over a satellite image base map using GIS software. This digitizing process will be explained later in the chapter. A similar decision process can be used to identify the appropriate source of future land-use data (Figure 3.1.2).

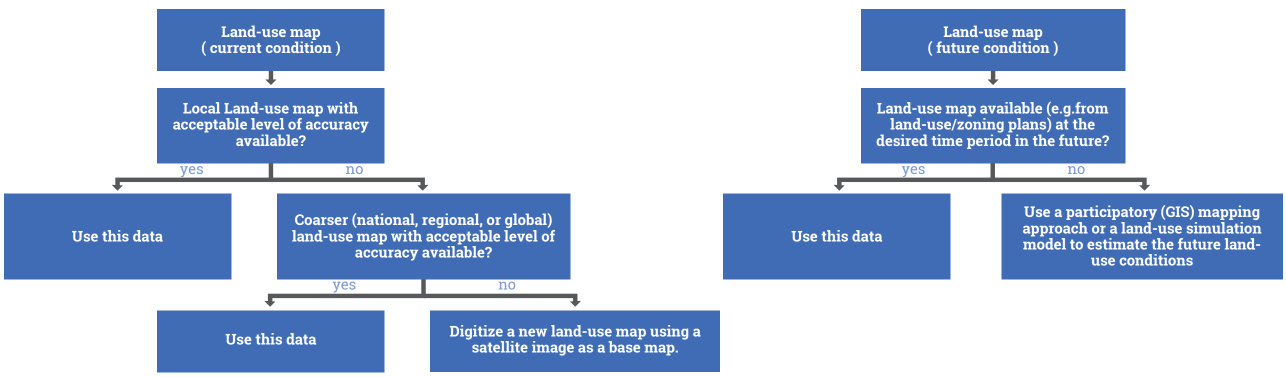


Figure 2.2. Process for identifying sources of current and future land-use data to use for impact assessments.

Tutorial

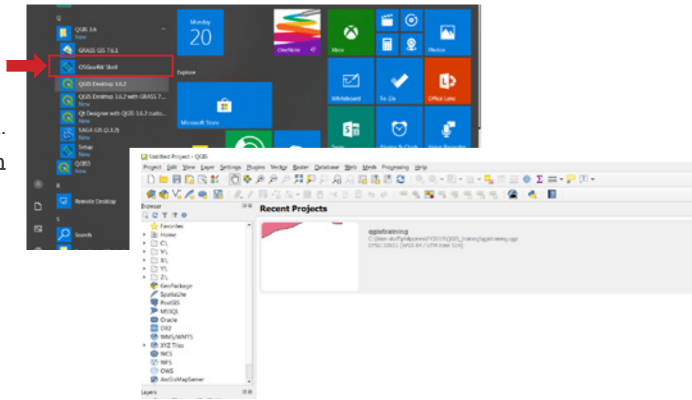
This tutorial focuses on the process for preparing current and future land-use maps of a case study site, using free GIS software. We have provided all of the data for this tutorial in the folder entitled "QGIS_training".

Step 1. Downloading and running QGIS

Much of the tutorial in this chapter is focused on QGIS, a free Geographic Information Systems (GIS) software package that is used commonly around the world. QGIS has a relatively simple user interface, and runs on Windows, Mac, Linux, and Android operating systems. You can downloaded the latest version of the software from https://www.qgis.org/en/site/. For the sake of this tutorial, we have already downloaded QGIS and provided it to you with this training package, so you can skip this downloading step.

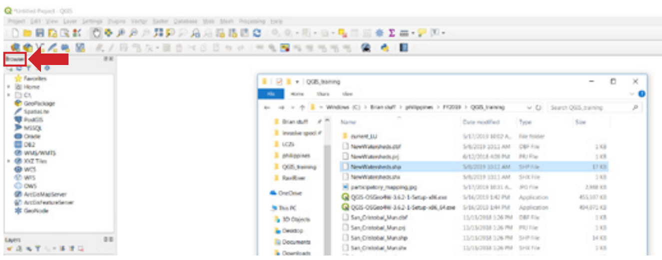
a To install QGIS on your computer, double-click the "osgeo4w-setup-x86_64.exe" file and follow the installation instructions. For this tutorial, we are using the version of QGIS for Windows operating systems.

b Open QGIS Desktop using the Windows Start menu. After QGIS opens, you will see a browser menu on the left, and recent projects in the main window.

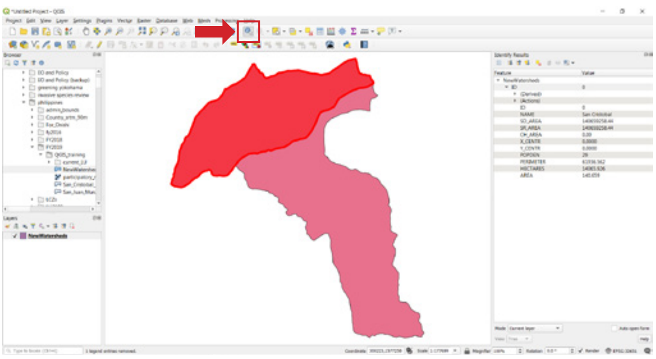


Step 2. Loading GIS data of the boundary of a sample study site.

a To install QGIS on your computer, double-click the "osgeo4w-setup-x86_64.exe" file and follow the installation instructions. For this tutorial, we are using the version of QGIS for Windows operating systems.



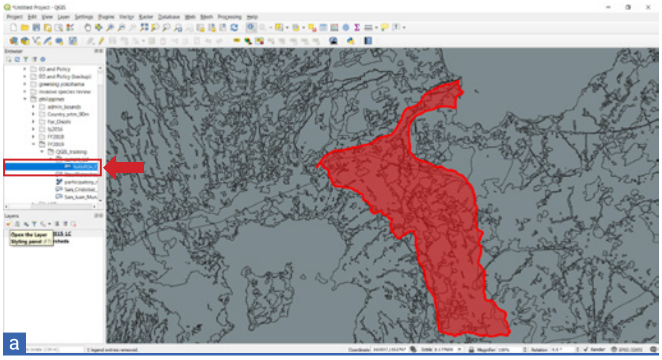
Step 3. Inspecting the data and modifying the layer style

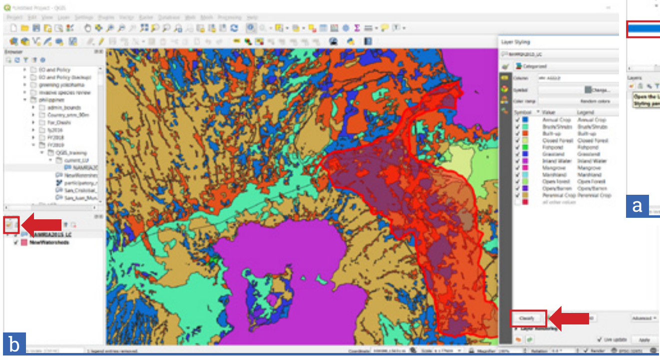


a You will see two watersheds, the San Cristobal watershed and the San Juan watershed. Check the details of the added files by clicking on the "Identify features" icon in QGIS. You can also check by right-clicking on "NewWatersheds" in the Layers menu, and selecting "Open attribute table". The "NAME" row shows the name of the watershed that the polygon contains, and the other rows show the size, area, and average population density of the watershed.

Step 4. Adding a current land-use map (“NAMRIA2015_LC.shp”) and visualizing each land-use class as a different color.

a Drag the data from the “current_LU” folder using Windows file explorer or the Browser window in QGIS



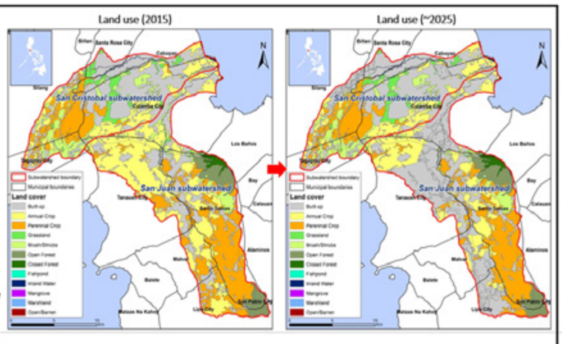


b For easier visualization, you will assign a unique color to the polygons representing each land-use class. To do this, click on the “NAMRIA2015_LC” map layer in the Layers window to highlight this layer, and then click the Layer Styling Panel icon . In the Layer Styling window, change the symbol type from “Single Symbol” to “Categorized”, and specify the “AGC12” column as the column containing the land-use information. Finally, click the “Classify” icon.

c Practice zooming in and out to the study area boundary using the magnifier and “pan” icons above the map window. Practice turning on/off the two map layers by checking on/off the check boxes in the Layers window, and re-ordering the maps by dragging them up and down in the Layers window. Finally, practice changing the colors of each land-use class by clicking the color box next to it in the “Symbol” column of the “Layer styling” window.

Step 5. Create a future land-use map based on the outputs of a participatory mapping activity.

In Step 4, we loaded a GIS shapefile containing the current land-use. For land-use change impact assessments, however, we also need a map showing the potential future land-use. This could be a land-use map based on your municipality’s land-use or zoning plan, which may already be in GIS format. If no future land-use/zoning map exists already, a common approach to understand the potential future land-use conditions of a watershed is to conduct a participatory land-use mapping activity with relevant local government staff (i.e. those involved in land-use planning processes) as well as any other relevant stakeholders. This kind of activity typically involves printing out a large poster-size map of the watershed, showing the watershed boundary, the administrative boundaries, the current land-use, the major roads and rivers, and other important geographic features. The local government staff then sketch the planned (or likely) future land-use changes using colored markers. To translate this analog data to digital GIS format, we can finally digitize it using GIS software.

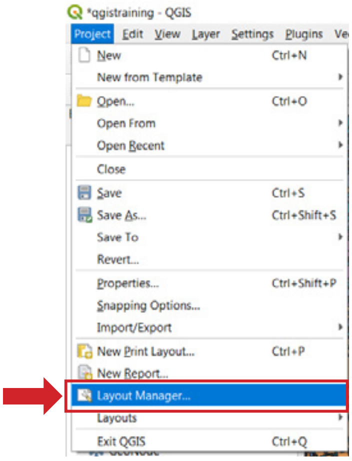


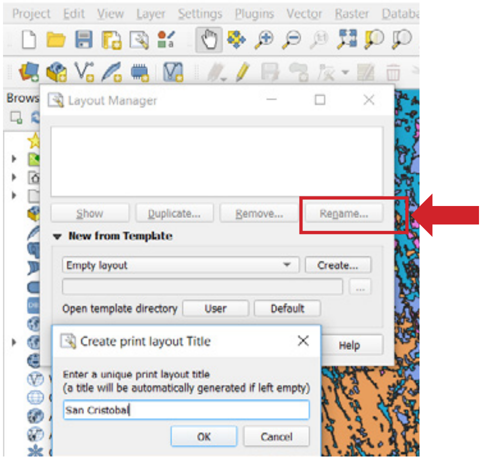
Participatory mapping activity conducted with local government officials (top). Current and future land-use maps in GIS format, generated by digitizing the participatory mapping result (right).

5.1. Creating a current land-use map to use as a basis for participatory mapping activity

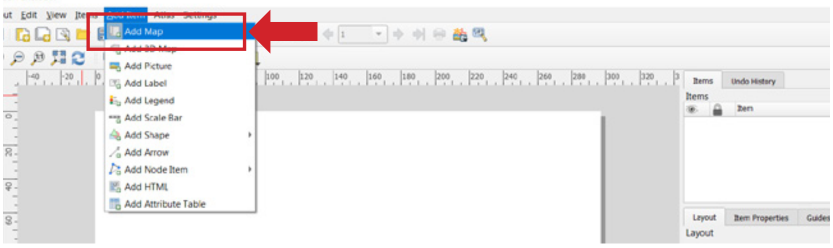
Let's create a very basic current land-use map that could be printed out and used for a participatory mapping activity.

a Click on the "Project" menu, then click "Layout Manager…" from the dropdown box. A Layout Manager window will appear. Under **New from Template** header in this window, make sure "Empty layout" is selected and click the "Create…" button. In the "Creat print layout Title" window that appears, please enter "San Cristobal" as the title, and then click "OK".

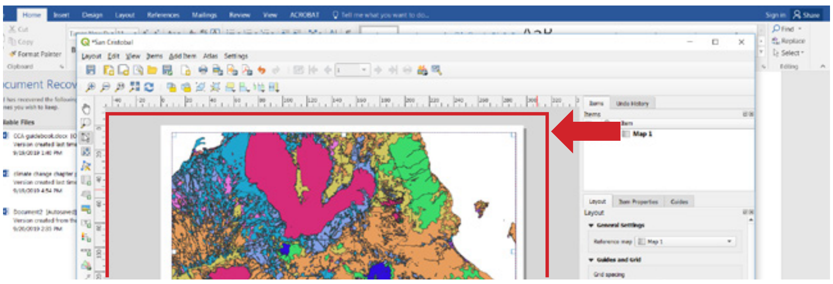




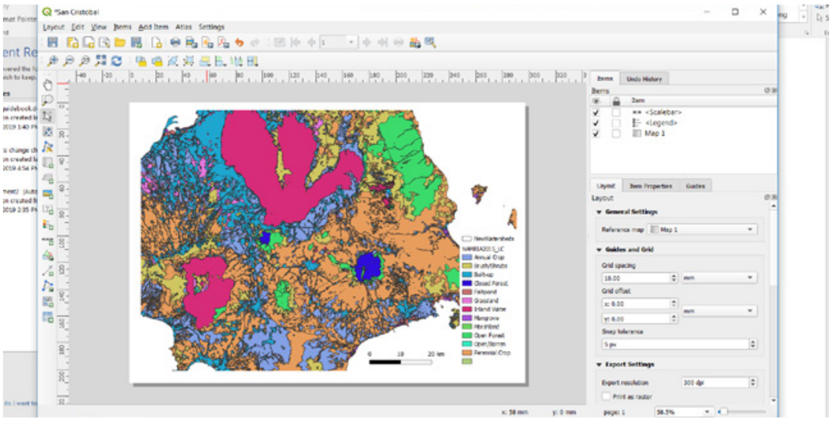
b A new window entitled "San Cristobal" will appear. [If you close this window, you can open it again by clicking again on the "Project" menu, and then clicking "Layouts", and "San Cristobal".] In the next steps, you will create the current land-use map layout for San Cristobal watershed using the tools in this window.



c To add a map to the layout, click on the "Add Item" menu, and click "Add Map" in the dropdown box. A crosshairs will appear for your mouse pointer, and you can click and drag a rectangle that will display the GIS layers in this layout. You can move the map or resize it by dragging or stretching the rectangle.

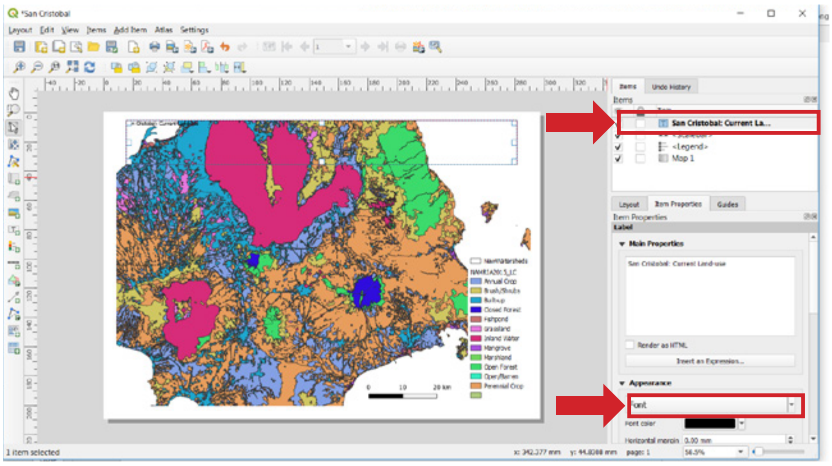


d Add a map legend by clicking on the "Add item" menu and clicking "Add legend" in the dropdown box. You can draw a rectangle to indicate where you want the legend to go. Usually, map legends go in one of the corners of the map layout, where they will not obstruct the GIS layers shown in the map.



e Add a scale bar to the map by clicking on the "Add item" menu and clicking "Add Scale Bar" in the dropdown box. You can draw a rectangle to indicate where you want the scale bar to go. Usually, scale bars also go in one of the corners of the map layout, where they will not obstruct the GIS layers shown in the map. Your layout window will look something like this after adding the Legend and scale bar:

f Add a title for the map. Click again on the "Add item" menu, and click "Add label" in the dropdown box. Drag a rectangle in the top part of the layout window where the title will go. By default, the title text is "Lorem ipssum". Let's change this title by right-clicking on "Lorem ipsum", and clicking "Item properties" from the dropdown box, and then entering a new title: "San Cristobal: Current Land-use". You can make the text larger by clicking on the "Font" menu, and selecting a larger font size (try size 36 font).



g Zoom into your area of interest in the map (e.g. the two watersheds). If you forgot how to zoom in, refer to step 4 (c)

h Save the layout by clicking the "Layout" menu, and clicking "Save project". You can also click the disk icon below the Layout menu to save.

i Finally, save the layout as a .pdf file by clicking the "Layout" menu, and clicking "Export to pdf" in the dropdown box. Name the file "San Cristobal watershed" and save it in the "QGIS_outputs" folder.

Now you have completed the process of creating an existing land-use map of a watershed, which can be printed out and used to conduct a participatory mapping activity! The actual participatory mapping can be done by providing markers of different colors to the participants, and asking them to draw out their planned future land-use changes in different colors. For example, they might digitize new planned urban developments in red, new parks or other green spaces in green, and new agricultural areas in yellow. Once this is completed, this analog data will need to be digitized into a new GIS layer.

Step 5.2. Digitizing the future land-use map created through a participatory mapping activity.

In the next steps, we will practice the digitizing process in QGIS so that you can digitize a future (or current) land-use map using GIS software.

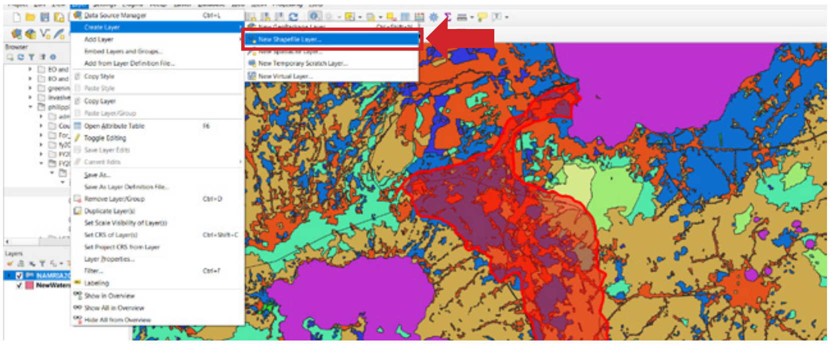
a Open the Layer menu, click "Create Layer", then click "New Shapefile Layer".

b Set the file and file path by clicking the [...] icon. Please name the file "Future_LU.shp", and place it in the "QGIS_training" folder.

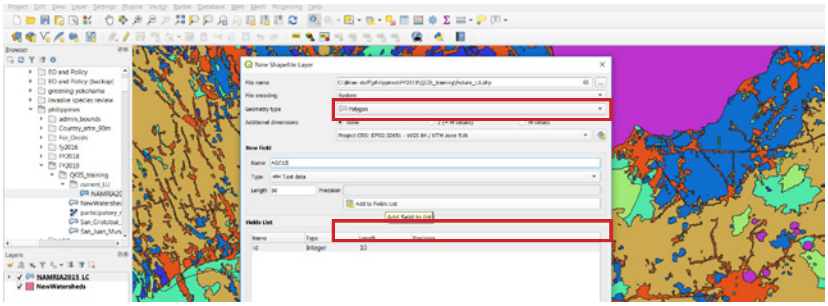
c Change the geometry type from "Point" to "Polygon".

d For additional dimensions, specify "None".

e Set the coordinate system and map projection to match the other GIS datasets (WGS 1984, UTM Zone 51N).

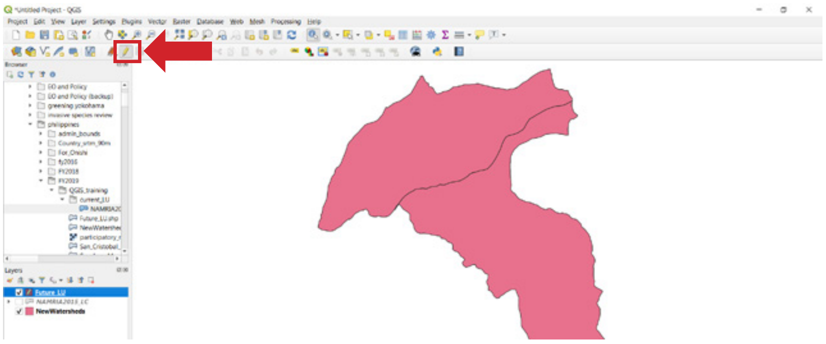


f Add a New Field to the file, called "AGC12". This field will contain the future land-use class information of each polygon that you will digitize. Set the Type to Text data, and the Length to 50. Click the "Add to Fields List" icon.

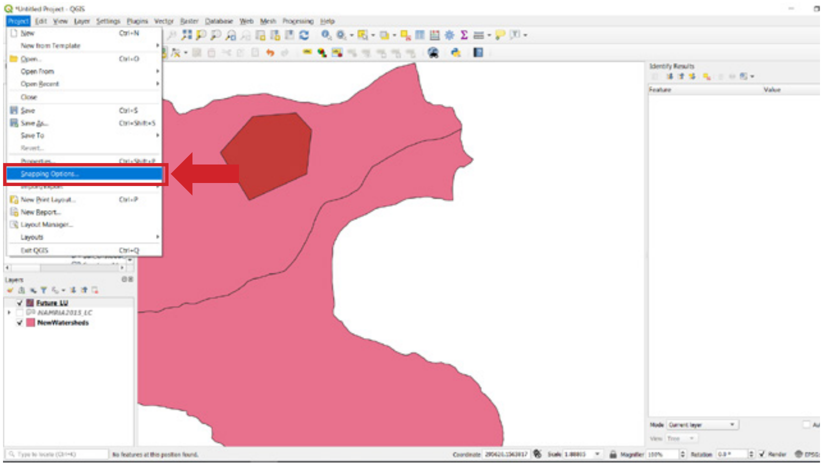


For now, this is just an empty shapefile. As the next step, we need to digitize polygons representing the future land-use of the watershed.

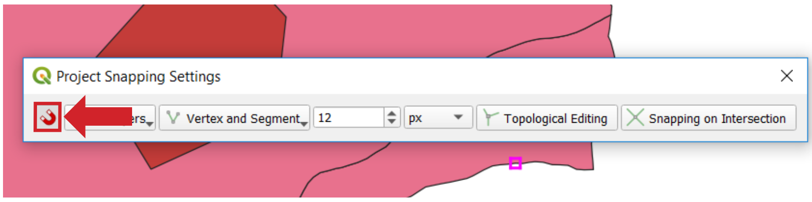
g Make sure everything matches the screenshot below. Then click "OK"



h Highlight the "Future_LU" layer in the Layers window, and click the Toggle Editing icon



i Try digitizing a new polygon representing the "Built-up" land-use class. Click the Add Polygon Feature icon Left click in the map display at a location where you'd like to start digitizing a polygon feature, then keep left clicking to add vertices (corners) of the polygon. When you've got the shape you want, right click to close the polygon. For this exercise, just try adding 5-6 vertices for the polygon, like the example shown below. (If you aren't happy with the polygon you made, and want to redo it, click the Undo icon). Add a unique ID number (1) and a land-use class (Built-up).



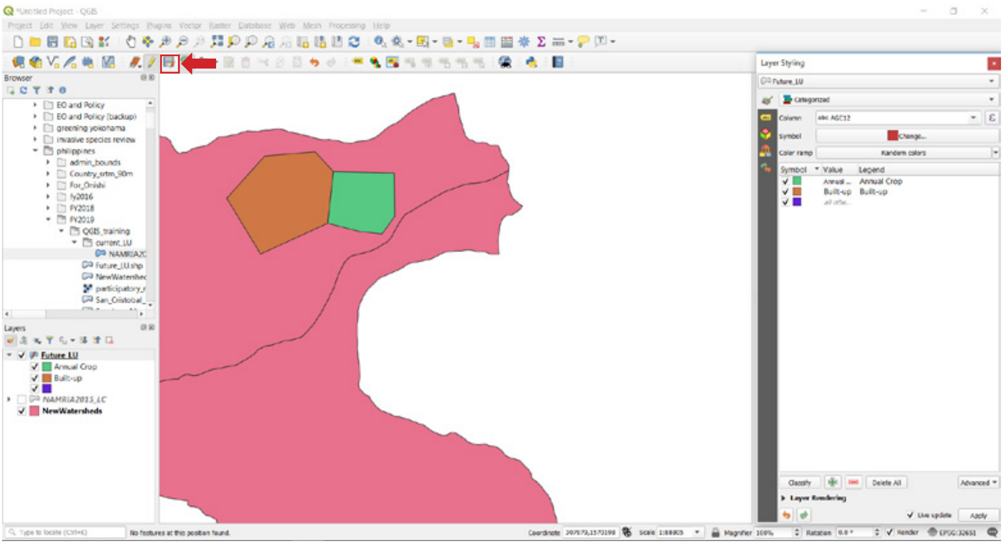
j Turn on "Snapping" to that the digitized polygons snap to one another, to allow for easier mapping. Click the "Project" menu, then "Snapping Options".

k Click the "Enable Snapping" icon. Choose "Vertex and Segment". This will ensure that polygons you digitize will snap to the existing polygons, and help avoid topological errors like overlapping polygons or gaps between polygons.

l Digitize another polygon with 5 vertices, this time of an "Annual Crop" land-use feature. Digitize it adjacent to the "Built-up" polygon you digitized earlier to practice snapping, and assign it an ID of 2.

m Try digitizing a few more polygons of the other types of land-use features. Assign a different color to each land-use class in this new layer. Go back to Step 4(b) if you need to refresh your memory of how to do this.

n Finally, save your edits by clicking on the "Save Layer Edits" icon!!!!



Congratulations, you've learned the basics of displaying and digitizing land-use data in QGIS!

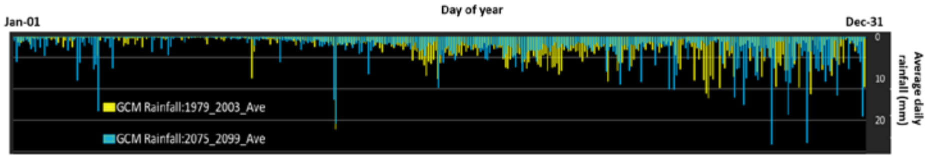
For a longer and more general QGIS tutorial, please also check the QGIS website: https://docs.qgis.org/3.4/en/docs/training_manual/create_vector_data/create_new_vector.html.

In the next steps, we will practice the digitizing process in QGIS so that you can digitize a future (or current) land-use map using GIS software.

References

Soil Conservation Service. (1986). Urban Hydrology for Small Watersheds. In Technical Release 55.

Chapter 3: Climate change scenario analysis



Overview of this chapter

Due to increasing greenhouse gas (GHG) concentrations in the atmosphere, the Earth's climate is changing at the global scale. The main change is increased global temperatures, while the magnitude of the temperature changes varies from location to location. Climate change is affecting the water cycle as well, leading to more rainfall in some regions and less in others, and changing the seasonal rainfall patterns in many places (causing more/less drought or flooding, depending on the geographic region). To better understand local climate changes, projections from global climate models (i.e. general circulation models; GCMs) or regional climate models (RCMs) are typically downscaled using statistical approaches, and then bias-corrected using local climate observation data. These downscaled and bias-corrected climate projections can be extremely useful for estimating the local impacts of climate change and identifying appropriate adaptation actions.

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Brian A. Johnson

After completing the chapter, you will be able to:

This chapter will introduce you to GCMs and downscaling, and show you how to access downscaled climate data.

- Understand what GCMs are and how they are generated;
- Download GCM data (future precipitation and temperature climate variables); and
- Visualize the climate change projection using QGIS software.

Main concepts

Climate change and its impacts

Climate change is caused by a variety of natural and anthropogenic factors. Some natural factors affecting climate include variations in solar radiation and the occurrence of volcanic eruptions. Human activities like burning of fossil fuels and deforestation, however, are believed to be the main drivers of climate change (due to increased concentrations of greenhouse gasses (GHGs) in the atmosphere).

Global climate change is disrupting the ways that people live and interact with their environment. Some of the impacts of climate change include the alteration of natural ecosystems, interruption of food production and water supply, damage to infrastructure, and human morbidity and mortality (e.g. from increased heat stroke, drought, or climate-induced disasters) (IPCC, 2014). The consequences of climate change are already becoming evident in terms of the changes in the amount, intensity and frequency of precipitation, and temperature in many parts of the world.

The hydrosphere is possibly the most negatively affected component of the Earth system. Considering freshwater as a finite resource, many scientific studies have focused on evaluating the effects of climate change on precipitation patterns and hydrologic regimes (Dore 2005, Kleinn et al. 2005, Abbs et al. 2007). These studies and other similar ones have highlighted the impacts of climate change on regional precipitation trends, which include increased flooding and drought as well as deteriorating water quality in many regions. Developing nations, many of which have inadequate infrastructure and/or water governance systems, are likely to be most significantly affected. Asia, having the highest gap between freshwater supply and demand, is expected to bear the brunt of these global changes.

Climate change projections

It is difficult to precisely predict the future climate at a specific location (e.g. city or town) due to uncertainties from climate models and various other sources. Understanding of the general trend of climate change and variability, however, is important for impact assessment and climate change adaptation. Climate projections are the main tools used to understand the expected impacts of climate change on different sectors of a country. Climate projections consist of a synthetic time-series of climate variables, such as daily or monthly precipitation and temperature. These climate projections are derived from general circulation models (GCMs), also called global climate models. A GCM is a mathematical model of the general circulation of the planet's atmosphere or oceans, and is based on mathematical equations that represent the physical processes described in figure 3.1. GCMs simulate the responses of changes in greenhouse gas concentrations, and provide estimates of climate variables in the future (Mishra and Herath, 2011).

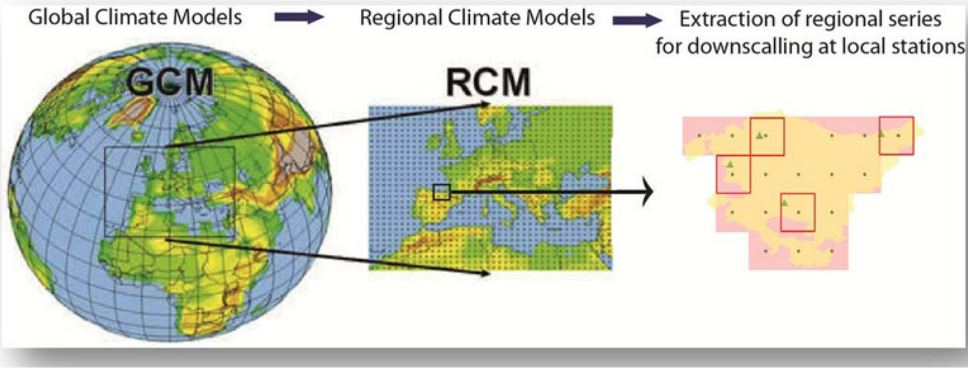


Figure 3.1. Climate model data (adopted from Aparicio and Zucker, 2015)

The GCM outputs are based on coarse resolution information (e.g. orography and elevation) for the generation of climatic variables, and are typically of a coarse spatial resolution (hundreds of km pixel size). However, forcing and circulation that affect local climate generally occur at much finer scale than that of GCM. Therefore, direct use of GCM outputs is not suitable for local climate change impact assessments, and hence spatial downscaling is required. Spatial downscaling is the process of deriving finer resolution (i.e. local) of climate data from the coarse GCM output for the climate change impact studies at local level. There are various downscaling techniques to convert the GCM outputs into locally applicable climate data. Although we will not discuss them in detail here, more information on downscaling methods can be found in Mishra and Herath (2011).

GCMs (and the downscaled data from them) are generated based on estimated future greenhouse gas emissions, which are calculated for different socioeconomic scenarios. The most widely-used of these socioeconomic scenarios are the so-called "representative concentration pathways" (RCPs), including RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (Moss et al. 2010). The RCPs are labeled according to the approximate global radiative-forcing level at 2100, with RCP 2.6 estimating the lowest amount of climate change by the year 2100, and RCP 8.5 estimating the highest amount of climate change by 2100.

Tutorial

Step 1. Downloading GCM data

Although GCM data can be downloaded from various sources, the most common one is from IPCC, as shown below.

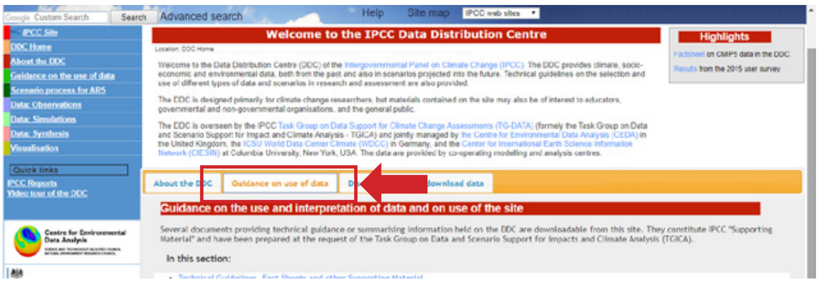
Figure 3.2. GCM data source from IPCC website

Please follow following steps to download GCM data from this site:

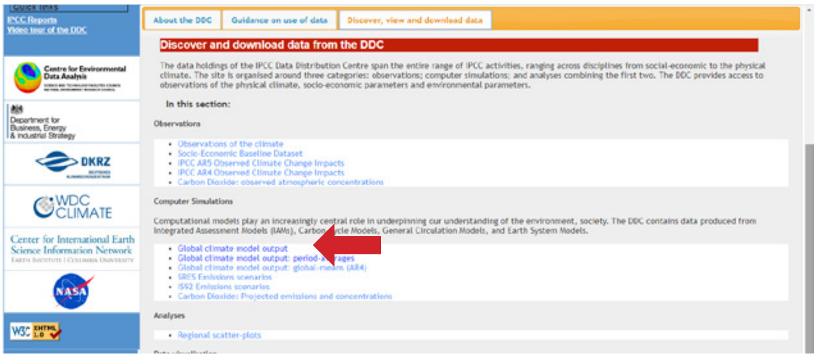
a Go to Intergovernmental Panel on Climate Change (IPCC) data distribution site: https://www.ipcc-data.org/

b Click the tab "guidance" to get different guidelines regarding how to select scenarios, fact sheet and scenario processes for IPCC Assessment Report 5 (AR5). This site has both past climatological data as well as projected data.

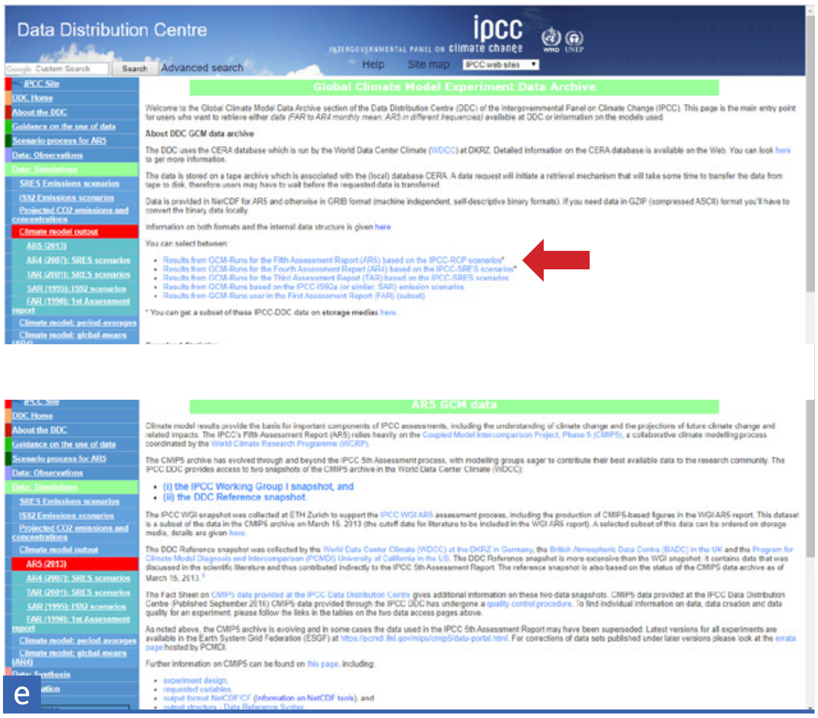
c Now click the tab discover, view and download data. This page has all the observed climate data, IPCC Assessment Report 5 (AR5) observed climate change impacts. Most importantly, this page has the global climate model outputs, as shown below.



d Click “Global Climate Model Output” link, and following page will open

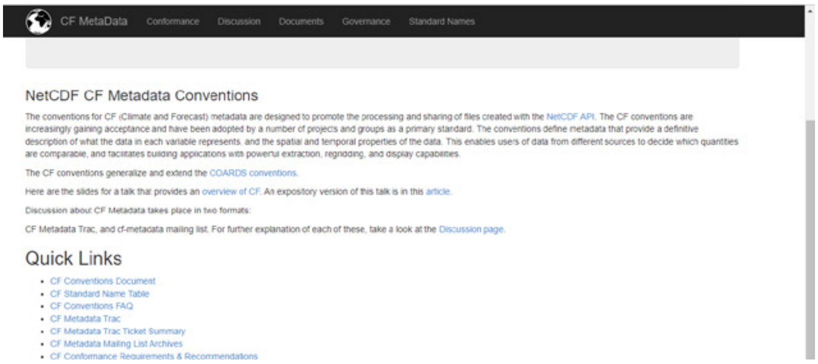


e Click “Results from GCM-Runs for the Fifth Assessment Report (AR5) based on the IPCC-RCP scenarios”, and following page will open.

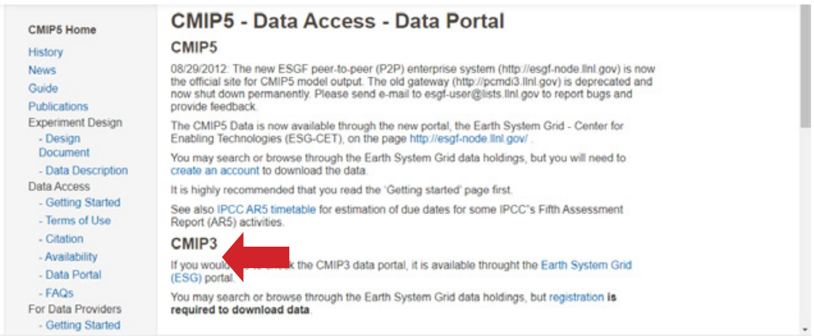


All the outputs shown here are from The IPCC’s Fifth Assessment Report (AR5), which relies heavily on the Coupled Model Intercomparison Project, Phase 5 (CMIP5), a large climate modelling process coordinated by the World Climate Research Programme (WCRP). The format for GCM output from all the RCP is in NetCDF/CF. NetCDF files can be opened and visualized in QGIS. For more details, please click the link output format NetCDF/CF (an overview is shown in the screenshot below http://cfconventions.org/).

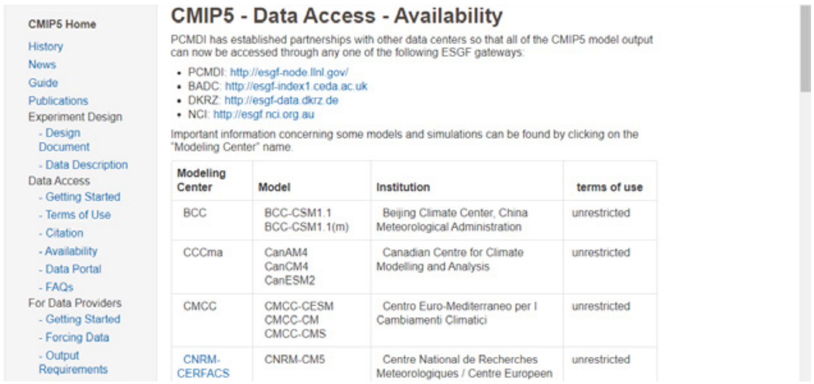
f To get data for a particular location, you need to click on following link:
https://pcmdi.llnl.gov/mips/cmip5/data-portal.html., and the page below will open:



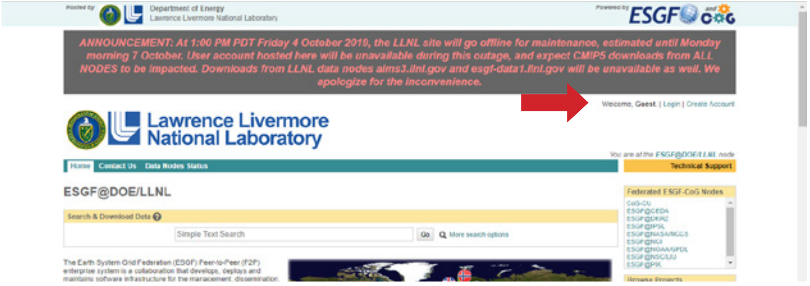
g Click "availability" on the left hand side menu and following page will open. Click the "PCMDI" link to go to the webpage for downloading the climate model data.



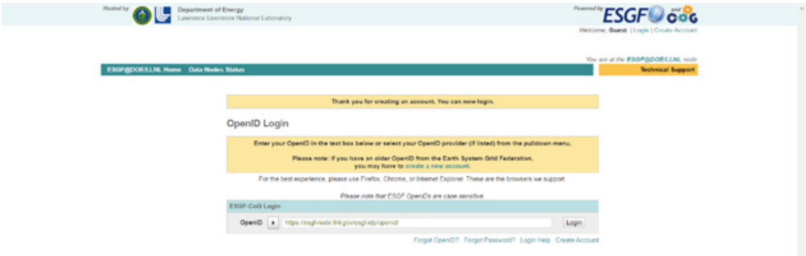
h Before downloading the data, first you need to create account by clicking "Create Account" in top right corner.



i After clicking the link, add the requested information (email address, user name, password, First/Last name, etc.) and you will receive an "OpenID Login". After inputting this OpenID and clicking the Login button, you can enter your user name and password.

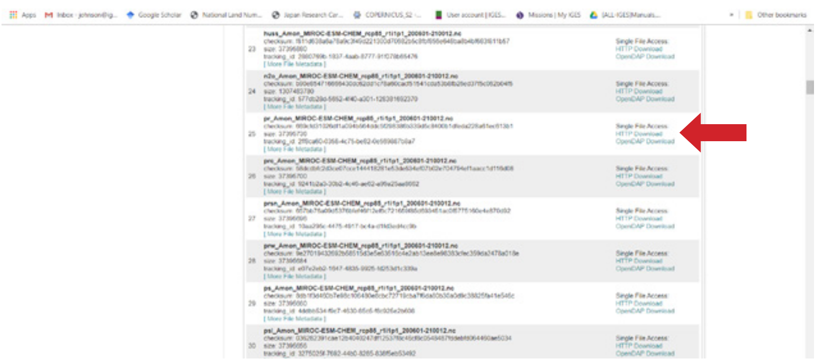


j After logging in, click on the CMIP5 link as shown below.



k The webpage below will open. Now you can choose which climate model and climate variables to download data for. Please click the + icon next to "Project" to expand the list of projects, and check on the box next to "CMIP5". Next, click the + icon next to "Experiment" and check the box for "rcp85". Finally, click the + icon next to "Variable Long Name" and check on the boxes next to "Air Temperature" and "Precipitation". Once all of these model components are selected, click the "Search" box and the available models will be displayed. The first model displayed is MIROC-ESM-CHEM, generated by the University of Tokyo, the National Institute for Environmental Studies, and the Japan Agency for Marine-Earth Science and Technology.

l Click on "List Files" for the first model in the list ("MIROC-ESM-CHEM")... To download the precipitation climate data ("Precipitation flux"), click the "HTTP Download" link for the variable number 25, "pr_Amon_MIROC....". To download the Precipitation data, click the "HTTP Download" link for the variable "prc_Amon..."



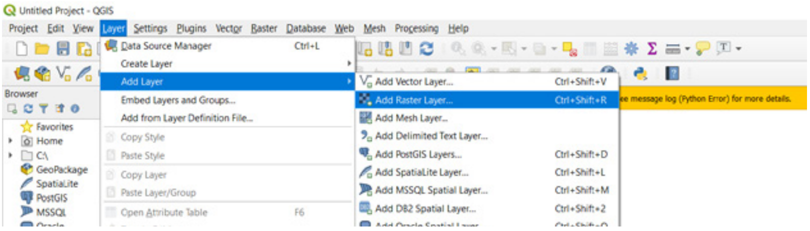
Step 2. Opening the climate model data in QGIS

Although GCM data can be downloaded from various sources, the most common one is from IPCC, as shown below.

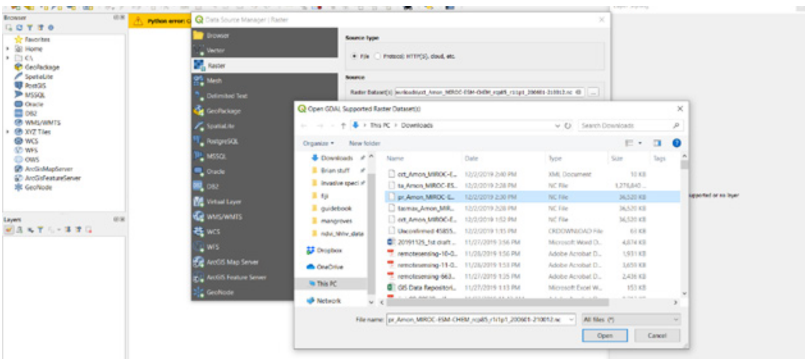
a Open QGIS software (See Chapter 2 if you don't remember how to do this!).

b Click on the "Layer" menu and then click "Add Raster Layer".

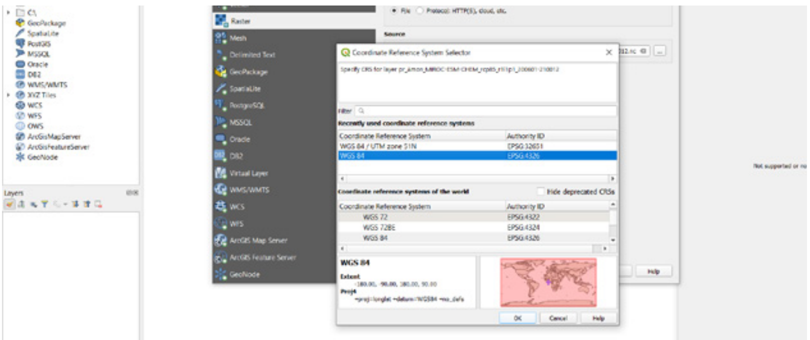
c Select the NetCDF file "pr_Anon...." and click "Open".



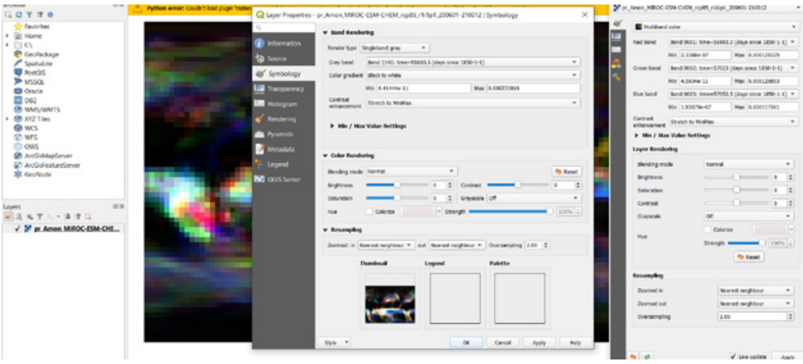
d Then click "Add". Then choose the desired coordinate reference system ("WGS 1984") and click "OK" to add the NetCDF layer in QGIS.



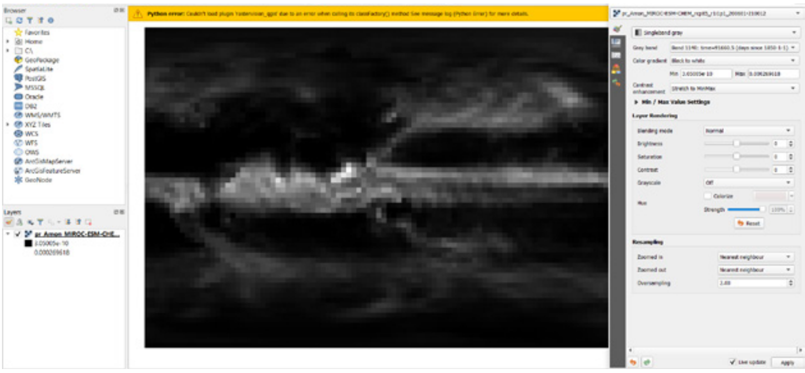
e To understand this layer, click on it in the "Layers" menu. By default, it shows as a "Multiband color" image, with model results for 3 years shown as a color map.



f Change this to "Singleband gray" to visualize the climate model results for a single month. As you can see, the dates are indicated by the number of days since 01/01/1850 (January 01, 1850). Please select Band 1140: time =91660.5 (days since 1850-1-1), this corresponds to the month of December in the year 2100.



g As you can see, the resulting map shows the spatial distribution of precipitation for the month of December in the year 2100. To convert these precipitation flux measurements (in units of kg/m2/s) to average millimeters of precipitation per day, these values would need to be multiplied by 86,400. To convert to monthly precipitation, they would then be multiplied by the number of days in the month of interest (i.e. 31 in the case of December).



h Now try to download and display the data for the average maximum monthly temperature variable ("tasmax" variable)

Congratulations, you've learned how to download and visualize climate model data in QGIS!

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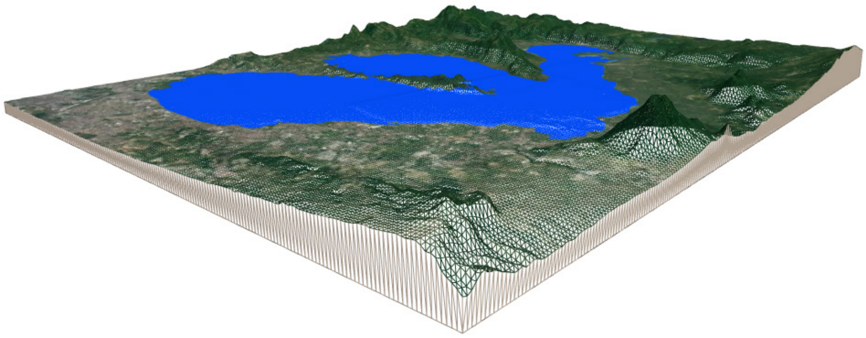
Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Timothy, R., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.W. (2010) The next generation of scenarios for climate change research and assessment. Nature, 463:747–756.

Chapter 4: Flood impact assessment using HEC-RAS software



Milben A. Bragais
Brian A. Johnson

Overview of this chapter

As discussed in Chapter 1 and Chapter 2, land-use changes and climate change often have impacts on flood hazard and exposure. This chapter gives an overview of tools and methods for flood modeling, which can help to understand and visualize the impacts of these changes on flood extent given a certain rainfall event. The chapter also provides a tutorial for simulating flood hazard using free software like QGIS, HEC-HMS, and HEC-RAS, providing step-by-step instructions on data preparation, rainfall and runoff curve generation, flood simulation, and flood extent computation. Using current and future (predicted) land-use maps as inputs in the flood modelling, you will be able to quantitatively compare the effects of land-use change as the flood extent.

After completing the chapter, you will be able to:

- Prepare data for flood modeling using QGIS software;
- Generate rainfall and runoff curve using HEC-HMS
- Conduct hydraulic modeling using HEC-RAS software to simulate the water movement and flood extent under two land-use scenarios;
- Compare the flood extent of the two scenarios in a simple overlay visualization

Main concepts

Flooding is one of the most significant climate-related hazards globally, so simulation and mapping of flood hazards is critical for disaster risk reduction and climate change adaptation efforts. The availability of free software and tools for flood modeling and visualization like QGIS, HEC-HMS, and HEC-RAS make it possible to conduct flood hazard impact assessments and use the results for science-based decision, e.g. to improve local land-use plans, disaster plans, and climate change adaptation plans to make the landscape less susceptible to flooding.

The flood modelling process requires a lot of data preparation using GIS. One of the best tools for this is the free and open-source GIS software known as QGIS, introduced in Chapter 2. This application enables the user to store, view, edit, analyze, and visualize geospatial data. It helps flood modelers to handle data efficiently and prepare input that can be opened across any GIS and flood modelling platforms. Along with QGIS, HEC-HMS and HEC-RAS are additional free softwares that offer hydrologic and hydraulic modelling capabilities, respectively.

HEC-HMS, or the "Hydrologic Engineering Center, Hydrologic Modeling System" is a numerical model that simulates watersheds and channels to predict the flow, stage and timing of runoff, or simply the generation of a rainfall and runoff curve. HEC-HMS was developed by the United States Army Corps of Engineers, and is designed to simulate the complete hydrologic processes of watershed systems. The output in this modelling, the hydrograph for a rainfall event, is used as an input to conduct hydraulic modelling using HEC-RAS software.

HEC-RAS, or the "Hydrologic Engineering Center, River Analysis System" is a computer program designed to model water flow through systems of open channels and surface profiles. As with HEC-HMS, HEC-RAS is also developed by the United States Army Corps of Engineers, and both are available online for free download and use (HEC-HMS: https://www.hec.usace.army.mil/software/hec-hms/downloads.aspx, HEC-RAS: https://www.hec.usace.army.mil/software/hec-ras/download.aspx). The main output of HEC-RAS is a map of the flood extent and the behavior of the flood water as it runs over the terrain. Using the current and future land-use/land cover maps as inputs in the flood modelling, researchers can analyze the effects of the land-use/land cover change on the flood extent under different development scenarios, as shown in the example in Figure 5.1.

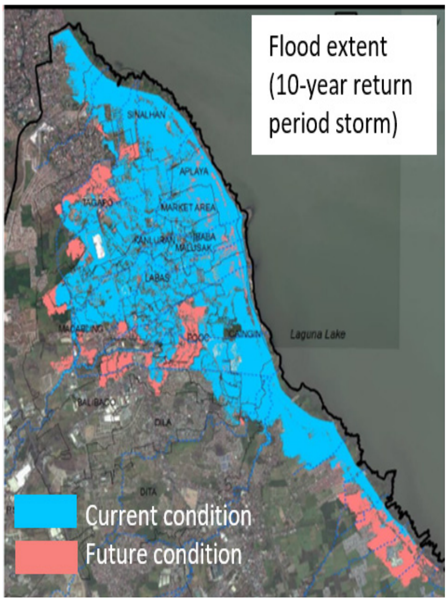


Figure 4.1. Comparison of flood extent under two different land-use scenarios (current condition and future planned land-use). Overlaying the results can show how the future condition will be impacted by planned land-use changes.

The remainder of this chapter is a tutorial for using QGIS, HEC-HMS, and HEC-RAS, which utilizes data from a case study site, the Silang-Santa Rosa subwatershed in the Philippines. Because this is a long tutorial, we have broken it down into three separate Modules. Module 1 focuses on data preparation using QGIS, Module 2 focuses on flood simulation using HEC-HMS and HEC-RAS, and Module 3 focuses on visualizing the outputs of the flood simulation using QGIS.

Tutorial

Module 1: GIS Data Preparation using QGIS

Objectives

The objective of this module is to inspect and / or prepare the GIS data needed for the flood modelling. Specifically, this module discusses how:

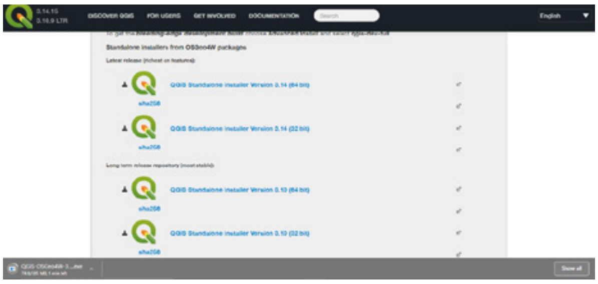
1. To download and install the needed software for the input preparation;
2. To check the integrity of the needed data by checking its properties and attribute table;
3. To prepare and format the data layers like the watershed boundary and river polylines; and
4. To organize other data to be used in the flood simulation like the discharge data in excel file.

Materials

1. QGIS version 3.14
2. QuickMapServices plugin
3. Digital elevation model (DEM)
4. Shapefiles (Land cover, Administrative boundary, River polylines)
5. River discharge data in excel file

Software Download and Installation

a Visit qgis.org to download the latest QGIS software version. QGIS is a free and open source geographic information system.

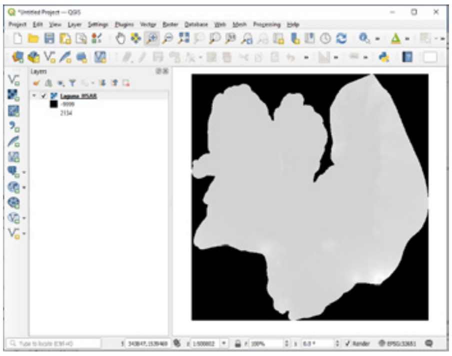
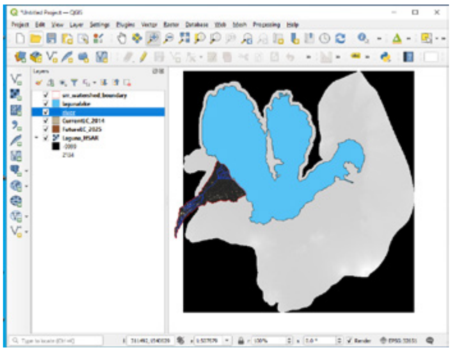


Select the version that suits your workstation. Click the download icon to start downloading the software.

b Install the version of QGIS that was downloaded. Click next to start the installation and click finish after the setup is completed.

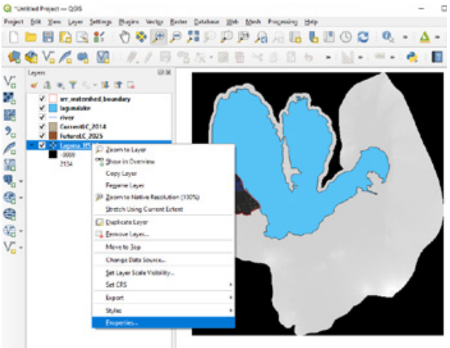
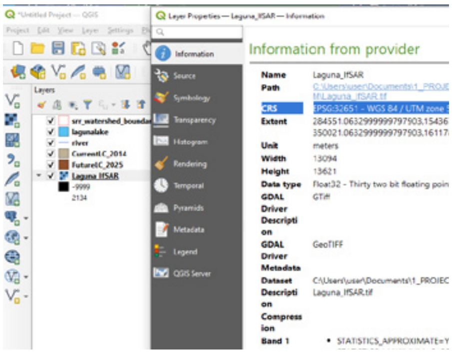
Data Inspection

a Open QGIS then load the given Raster (DEM[1]) and Vector (Watershed boundary[2], Laguna lake boundary[3], river polylines[4], current land cover polygon[5], and future land cover polygon[6]) data.

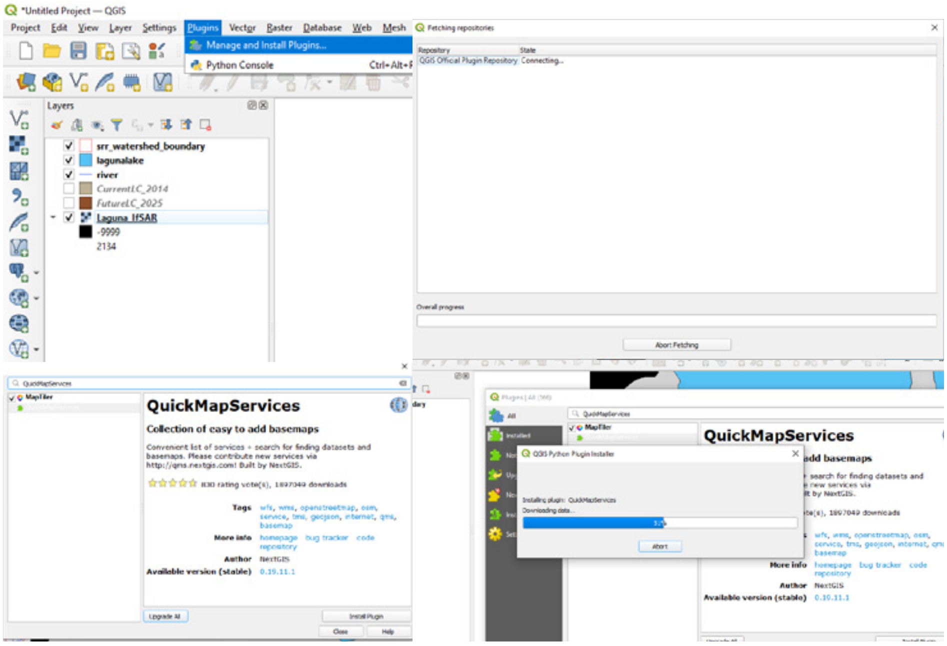
b Inspect the properties of each layer. Right click on the layer on the table of contents (TOC) then click properties. On the properties window, click the information tab and check the coordinate reference system (CRS) of the layer.

Data	Layer Name	CRS
RASTER • DEM	• Laguna_IfSAR.tif	EPSG:32651 - WGS 84 / UTM zone 51N – Projected
VECTOR • Watershed boundary shapefile • Laguna lake boundary shapefile • River shapefile • Current land cover shapefile • Future land cover shapefile	• srr_watershed_boundary • lagunalake.shp • river.shp • CurrentLC_2014.shp • FutureLC_2025.shp	EPSG:32651 - WGS 84 / UTM zone 51N – Projected

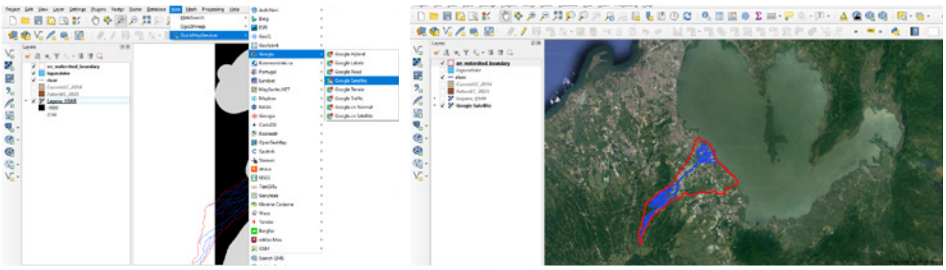



1 IfSAR (Interferometric Synthetic Aperture Radar) derived DTM with 5m x 5m resolution from National Mapping and Resources Information Authority (NAMRIA)
2 Silang-Sta. Rosa Subwatershed boundary from Laguna Lake Development Authority (LLDA) GIS data
3 Laguna Lake boundary extracted from the administrative data boundary downloaded GADM website
4 Silang-Sta. Rosa subwatershed tributaries digitized using Google Earth satellite image
5 2014 Land cover generated using Landsat 8 from the United States Geological Survey (USGS)
6 2025 Land cover from the participatory mapping activity participated by the Local Government Units in the subwatershed

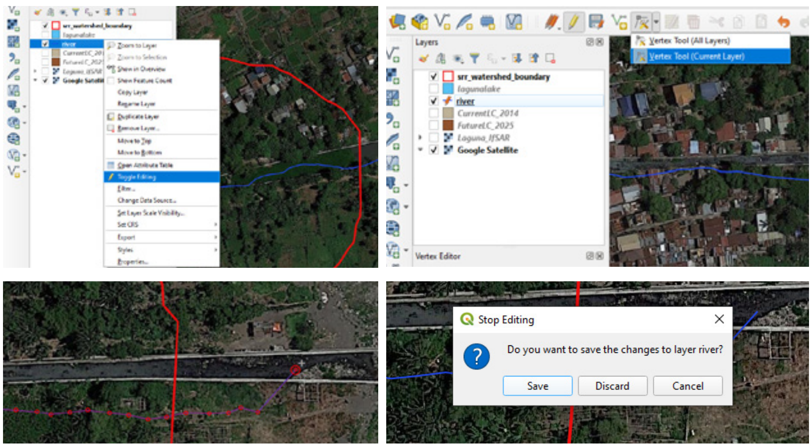
c Add plugin to load satellite image as basemap. Click the Plugins tab > click Manage and Install Plugins > the wait for the Fetching repositories window to finish fetching > click All on the Plugins window then type QuickMapServices on the space > click Install Plugin > wait for the installation to finish then click Close.



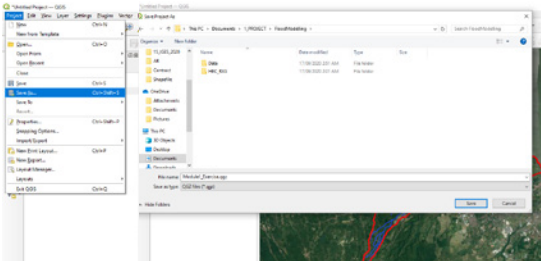
d Opening QuickMapServices plugin and loading of Google satellite image to see if the river network is plotted correctly in the map. Click Web > QuickMapServices > Google > Google Satellite. After the Google satelite is loaded in the Map display, please uncheck the other layers in the table of contents except srr_watershed_boundary, river, and Google Satellite.

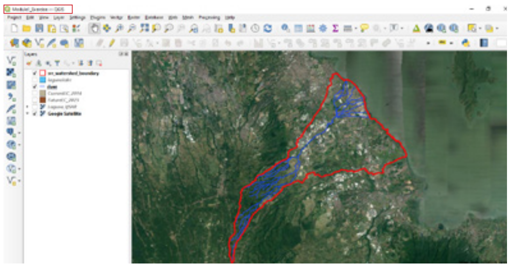


e Zoom in the Map display to see if the river network is plotted correctly in the map. Edit the river shapefile if there are incorrectly plotted polylines. Right Click the river layer in the TOC > click Toggle Editing. On the toolbars, click Vertex Tool (Current Layer) then hover your cursor in the river section to be adjusted. Adjust the vertext of the river section to correct part in the map. Once finished, click Toogle editing icon in the toolbar then click save to save and stop the editing mode.



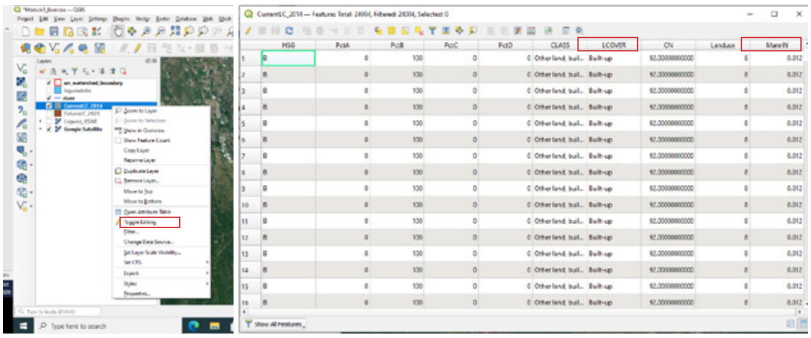
f Save the project as Module1_Exercise inside the Flood Modelling folder.



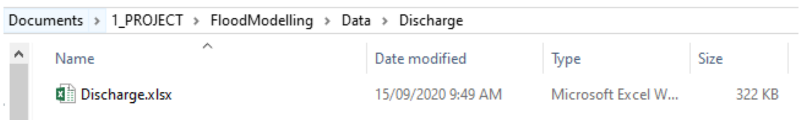


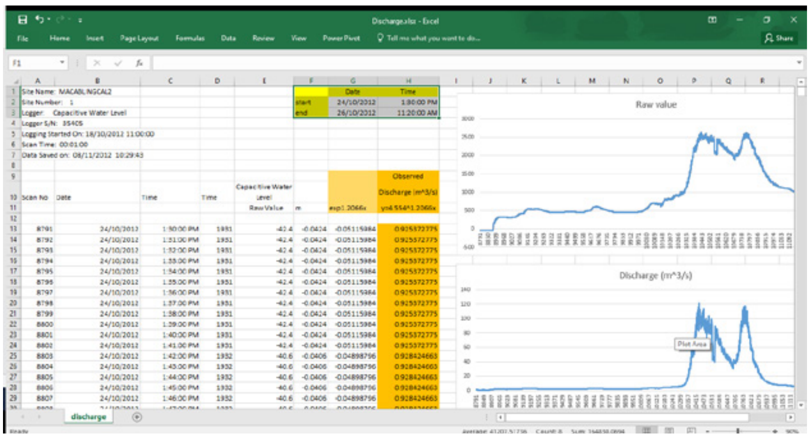
See that the project is now named as Module1_Exercise located in the upper rigt of the QGIS display.

g Checking the attribute table of the two land cover layers. Right click the CurrentLC_2014 layer in the TOC > click Open Attribute Table. Make sure that the table has LCOVER and MannN columns for the land cover classes and Manning's roughness coeeficient values, respectively. Do the same to check the attribute table of the FutureLC_2025 layer to see if it has LCOVER and MannN columns.



h Checking the river discharge data in Exel file collected using a capacitive water level logger installed in the dam inside the watershed. Take note of the recorded starting and ending time and date. Make sure to have the computed discharge voulume in cubic meter per second (m3/s)





Module 2: Flood Simulation using HEC-HMS and HEC-RAS

Objectives

The objective of this module is to conduct hydrologic and hydraulic simulation to compute and compare the flooded area under the current and future land cover data. Specifically, this module aims:

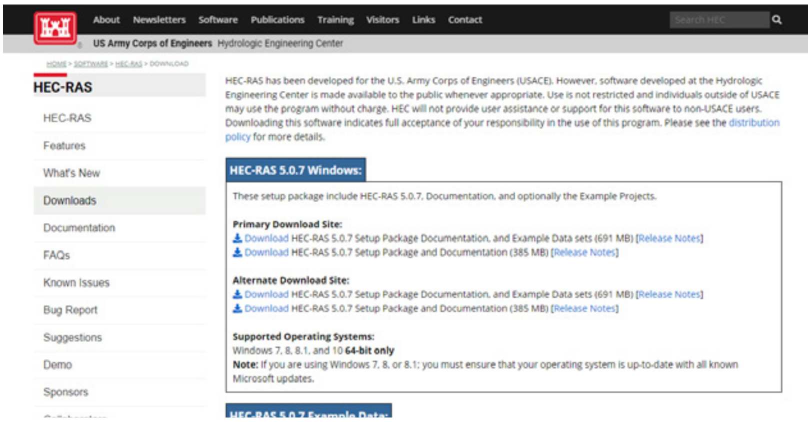
1. To download and install HEC-HMS and HEC-RAS to conduct the flood simulation;
2. To use the data from module 1 to generate hydrograph and prepare geometric and unsteady flow data input in the flood modelling software;
3. To conduct unsteady flow analysis between the current and future land cover layers as sources of the Manning's roughness coefficient values; and
4. To download and compute the resulting maximum flood extent generated after running both the unsteady flow analysis of the current and future land cover layers.

Materials

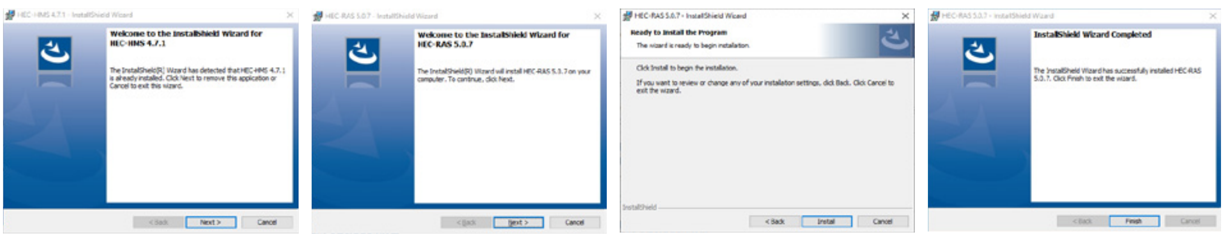
1. HEC-HMS version 4.7.1
2. HEC-RAS version 5.0.7
3. QGIS version 3.14
4. Data from Module 1 (DEM, Shapefiles, Rainfall, and Discharge data)

Software Download and Installation

a Visit hec.usace.army.mil website to download the latest HEC-HMS and HEC-RAS software versions.

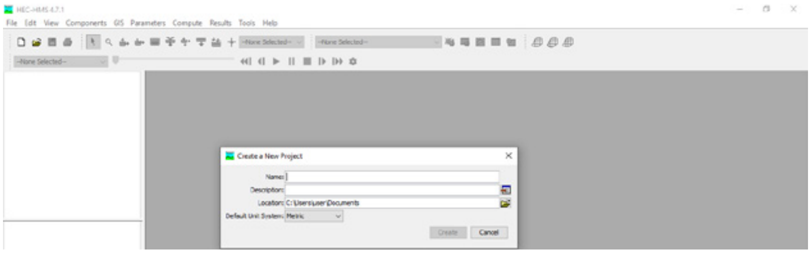


b Download and install the both HEC-HMS 4.7.1 and HEC-RAS 5.0.7 setup Packages and Documentation under the Primary Download Site for Windows. Double click the downloaded software > click Next > Choose I agree to the above Terms and Conditions for Use > click Next to define the Destination Folder > Click install the lastly, click the Finish button.

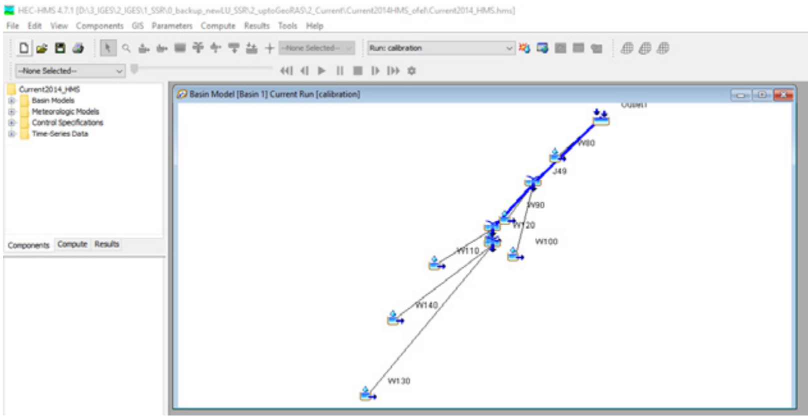


Creating a HEC-HMS Project

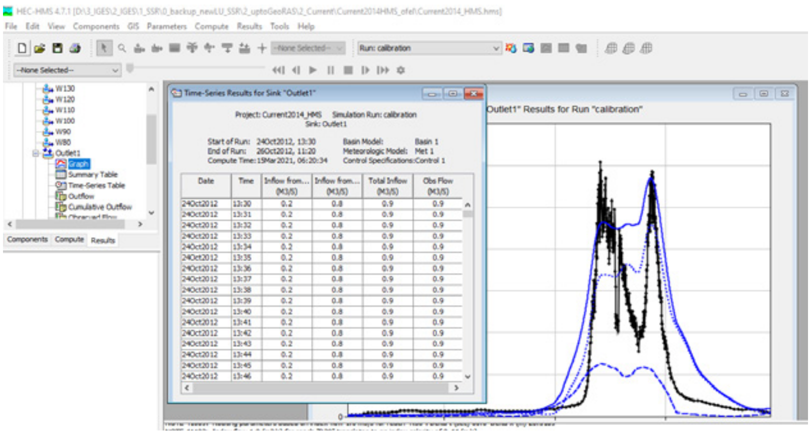
a Double click the HEC-MHS icon in the desktop. Under the File tab, click Save Project As > locate the folder to save the project > type SantaRosaRiver under the Title space as the project File Name.



b Import the basin model prepared using GIS software and create Meteorologic Models, Control Specifications, and Time-series Data under Components tab.

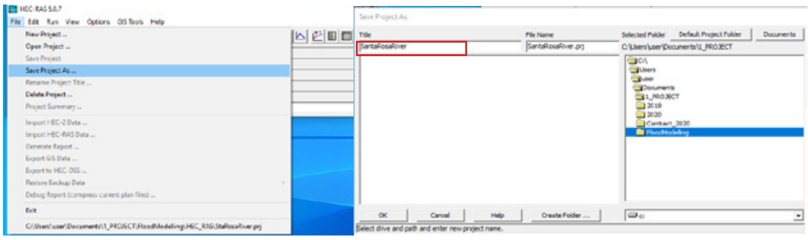


c Create simulation run using the Compute Tab > click Compute icon > copy the Predicted Inflow in the Time-Series Results table to be used in the hydraulic modelling.

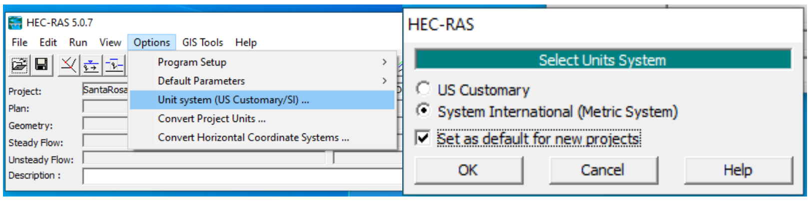


Creating a HEC-RAS Project

a Double click the HEC-RAS icon in the desktop. Under the File tab, click Save Project As > locate the folder to save the project > type SantaRosaRiver under the Title space as the project File Name.

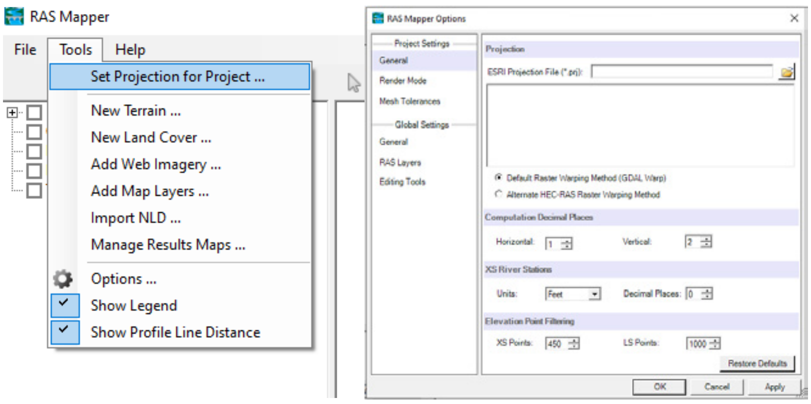


b Under the Option tab, click the Unit System (US Customary/SI)... Select System International (Metric System) and tick Set as default for new projects > click OK.

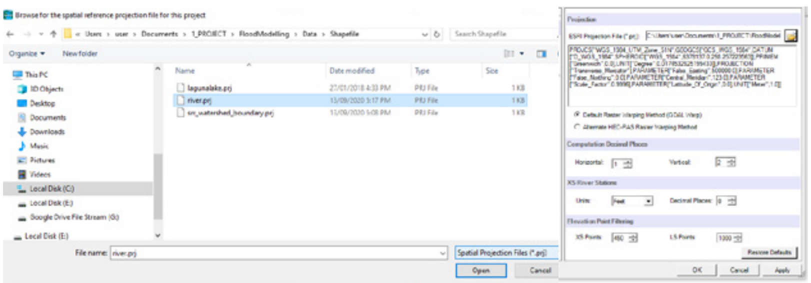


Loading Map layers using RAS Mapper

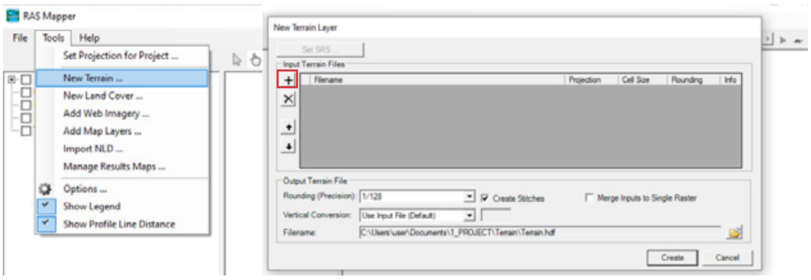
a Click this icon in the HEC-RAS window. Under the Tools tab of the RAS Mapper window, please click Set Projection for Project...Browse the data where you can find a projection file that can be used for your project area.



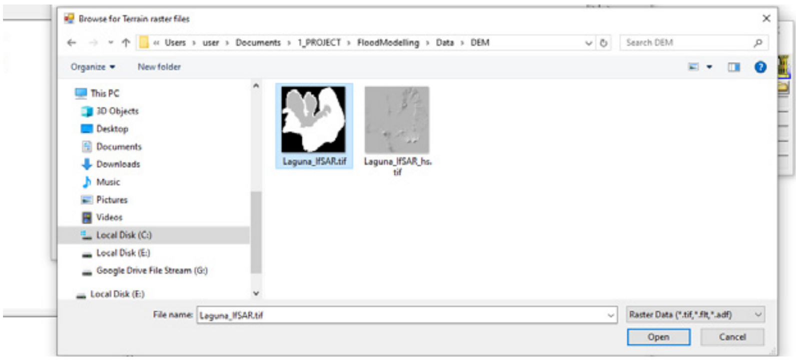
b Go to Flood Modelling >Data > Shapefile folder and select river.prj > click OK.



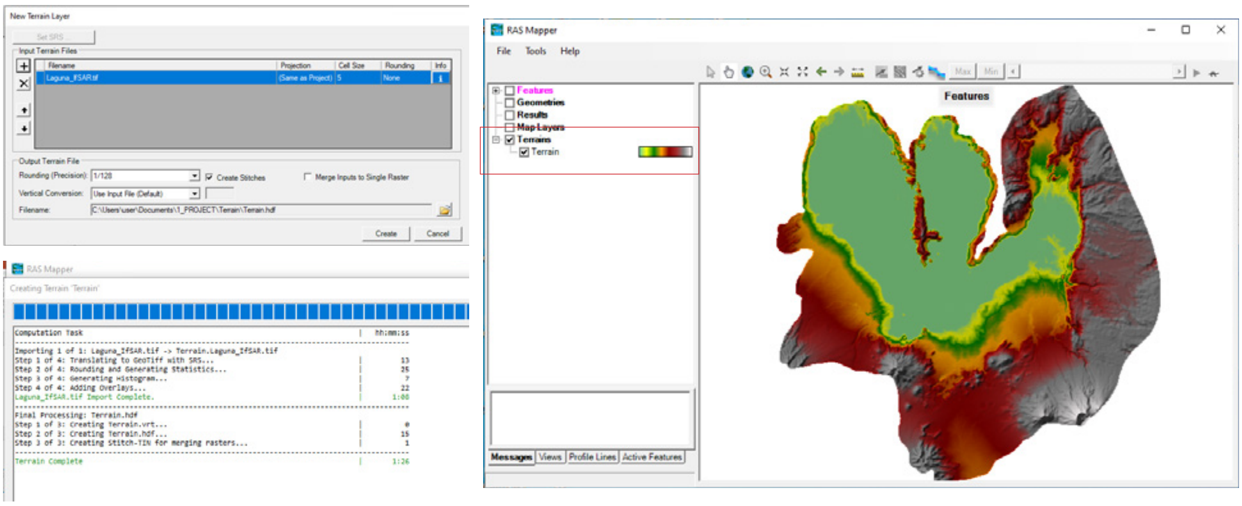
c Under the Tools tab of RAS Mapper, click New Terrain... > click the '+' sign to add the DEM data.



d Navigate to the Data folder then click Laguna_IfSAR.tif > click Open.

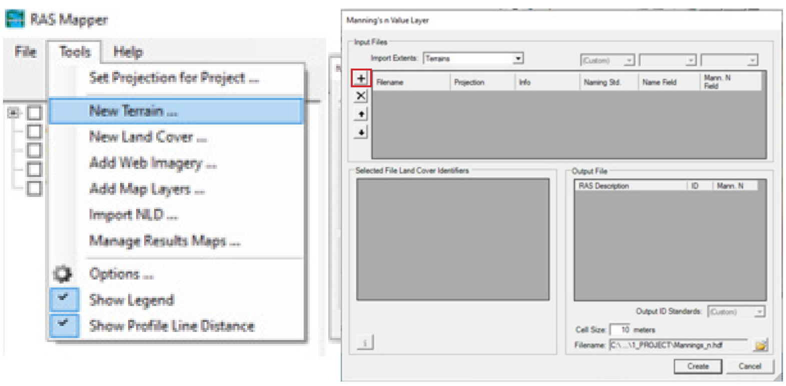


e Under the New Terrain Layers click Create. Wait as the RAS Mapper window create terrain then click the close button once done.

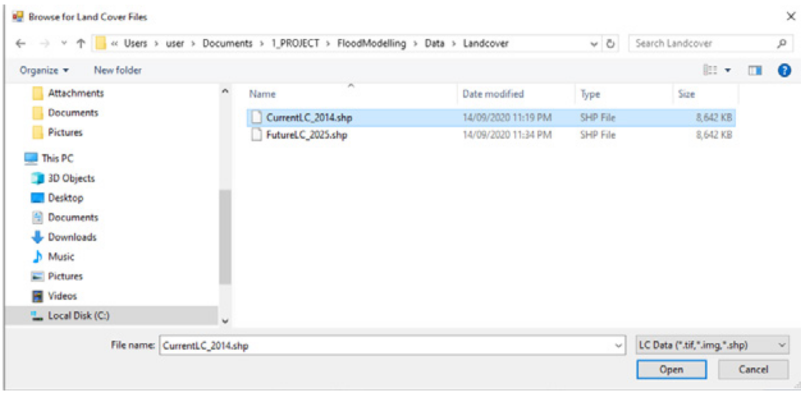


See that a Terrain layer is now on the TOC.

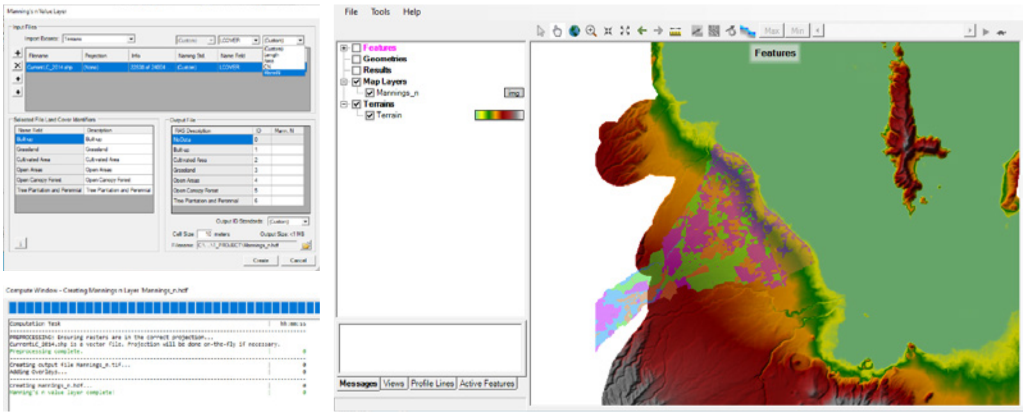
f Under the Tools tab of RAS Mapper, click New Land Cover... > click the '+' sign to add the current land cover layer.



g Navigate to the Data folder then click CurrentLC_2014.shp > click Open.

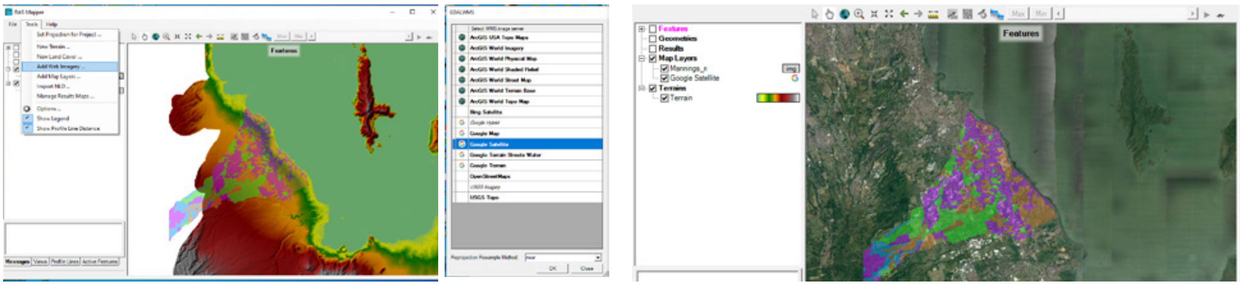


h Select LCOVER and MannN columns in the provided space > click Create > click Close.



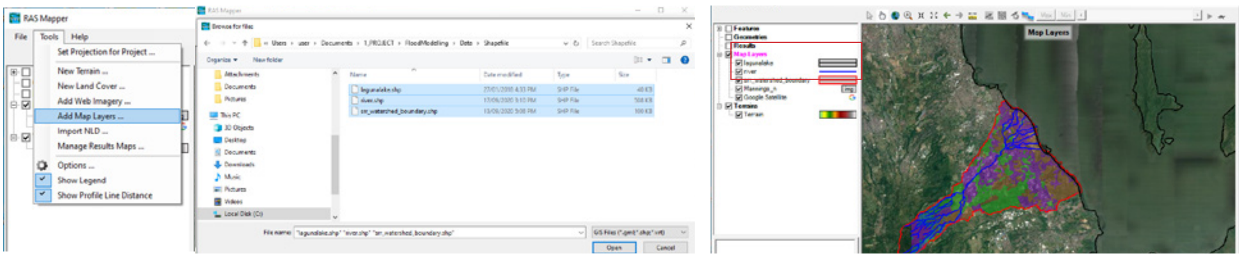
See that a new map layer, Mannings_n is now on the TOC.

i Under the Tools tab of RAS Mapper, click Add Web Imagery... > select Google Satellite > click OK.



See that Google Satellite layer is now on the TOC.

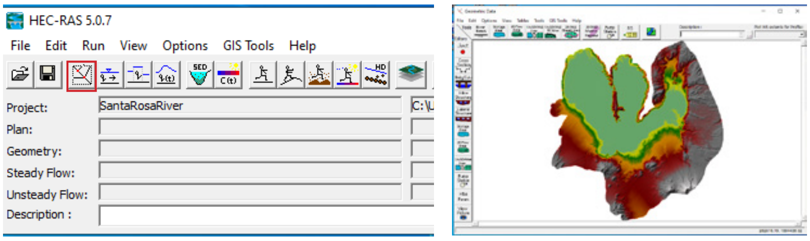
j Under the Tools tab of RAS Mapper, click Add Map Layers... > Navigate to the Data folder > under the Shapefile folder, select lagunalake.shp, river.shp, and srr_watershed_boundary. shp > click Open.



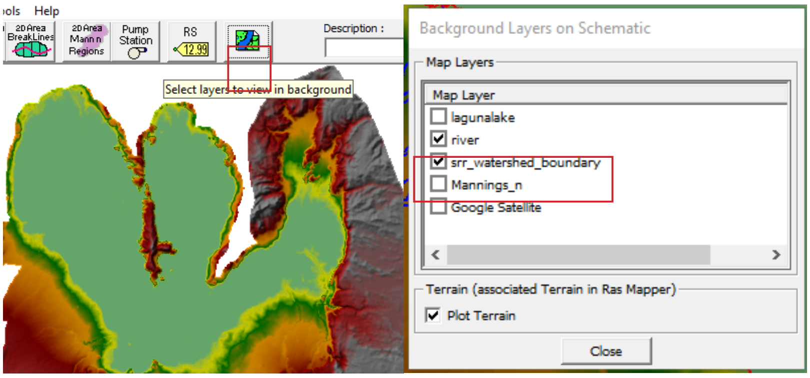
See that three new map layers are added to the TOC, Lagunalake, River, and srr_watershed_boundary.

Geometric Data Preparation

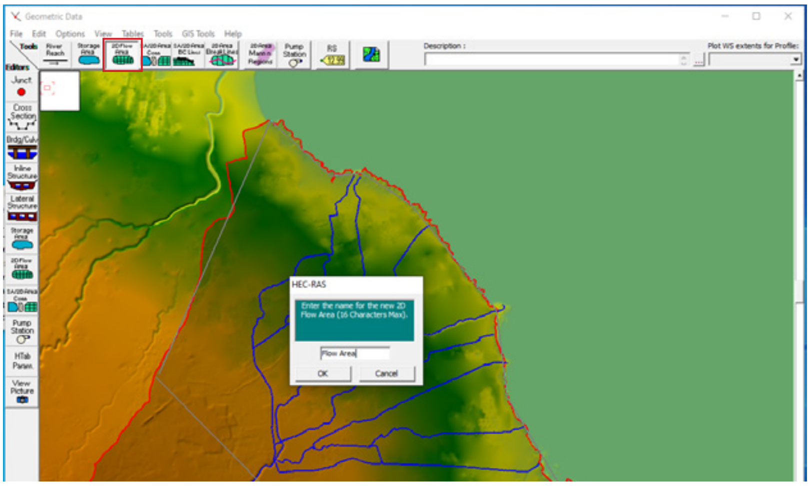
a Click the View/Edit geometric data icon.



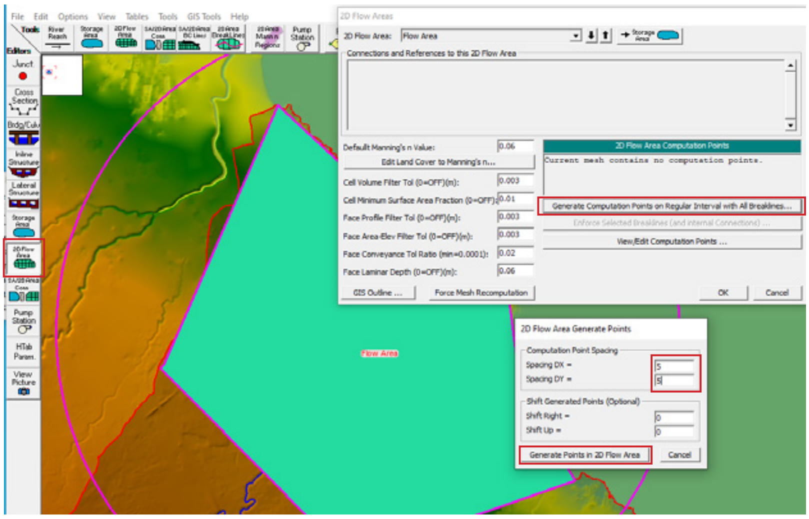
b Click Select layers to view in background icon > tick river and srr_watershed_boundary layers > click Close.



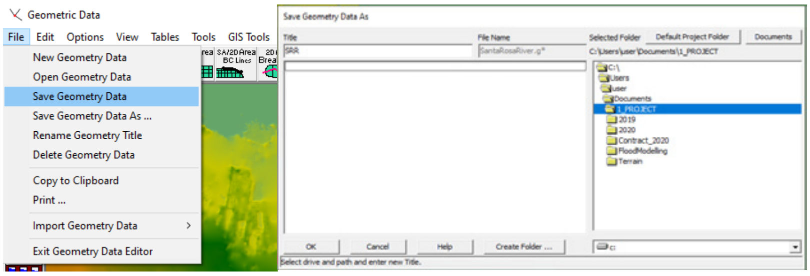
c Create 2D Flow Area. Zoom in to the downstream area. Click 2D Flow Area icon > trace the downstream area > double click to end digitizing > type Flow Area as the name for the created 2D flow area > click OK.



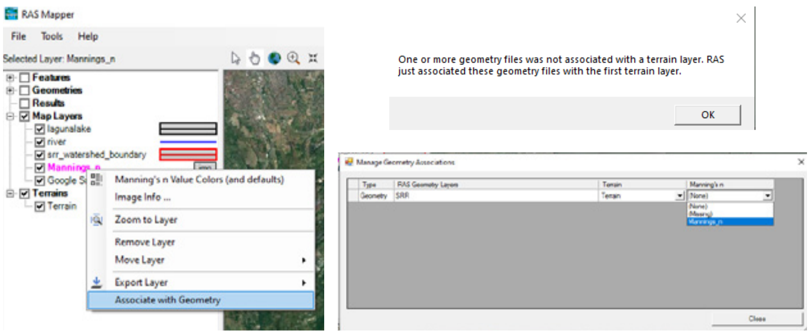
d Click Edit 2D Flow Areas > click Generate Computation Points on Regular Interval with All Breaklines... > type 5 for the Computation Point Spacing for both Spacing DX and Spacing DY > click Generate Points in 2D Flow Area > click OK.



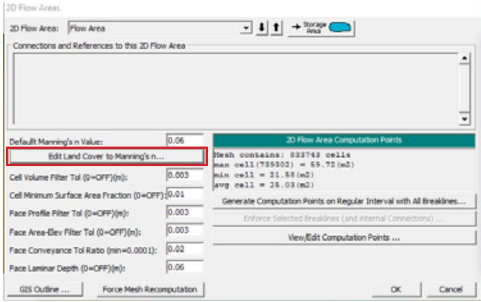
e Click File tab under in the Geometric Data window > click Save Geometric Data > type SRR as the Title of the Geometric Data > click OK.

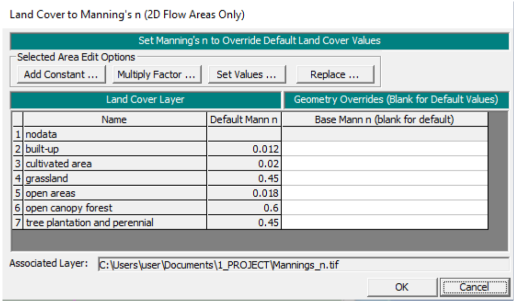


f Open RAS Mapper window. Right click Mannings_n > click Associate with Geometry > click OK > select Mannings_n in the manage Geometry Association window > click Close.

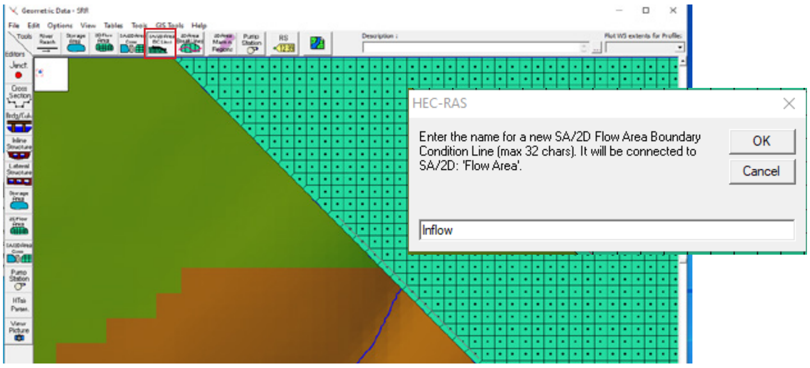


g Go to Geometric Data – SRR window. Click Edit 2D Flow Areas > click Edit Land Cover to Manning's n... > click OK.

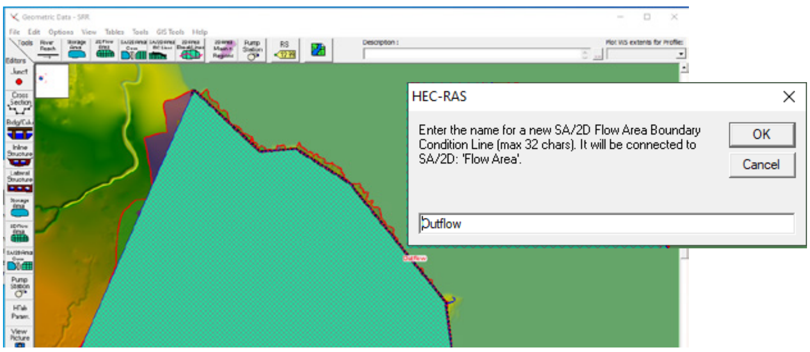




h Create Boundary Condition Inflow. Zoom in to the upper portion of the Flow Area. Click SA/2DArea BC Lines icon > trace a line across the river in the inflow area > double click to end digitizing > type Inflow as the name of the boundary condition > click OK.

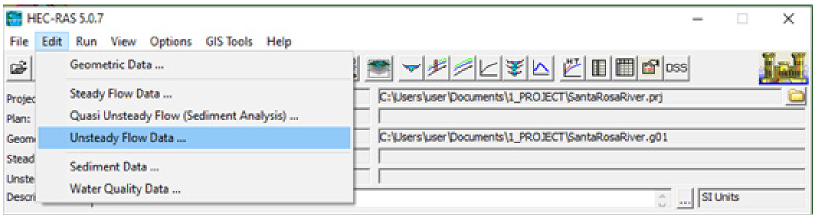


i Create Boundary Condition Outflow. Zoom in to the lower portion of the Flow Area. Click SA/2DArea BC Lines icon > trace a line across the boundary in the outflow area > double click to end digitizing > type Outflow as the name of the boundary condition > click OK > go to File tab > click Save Geometry Data.

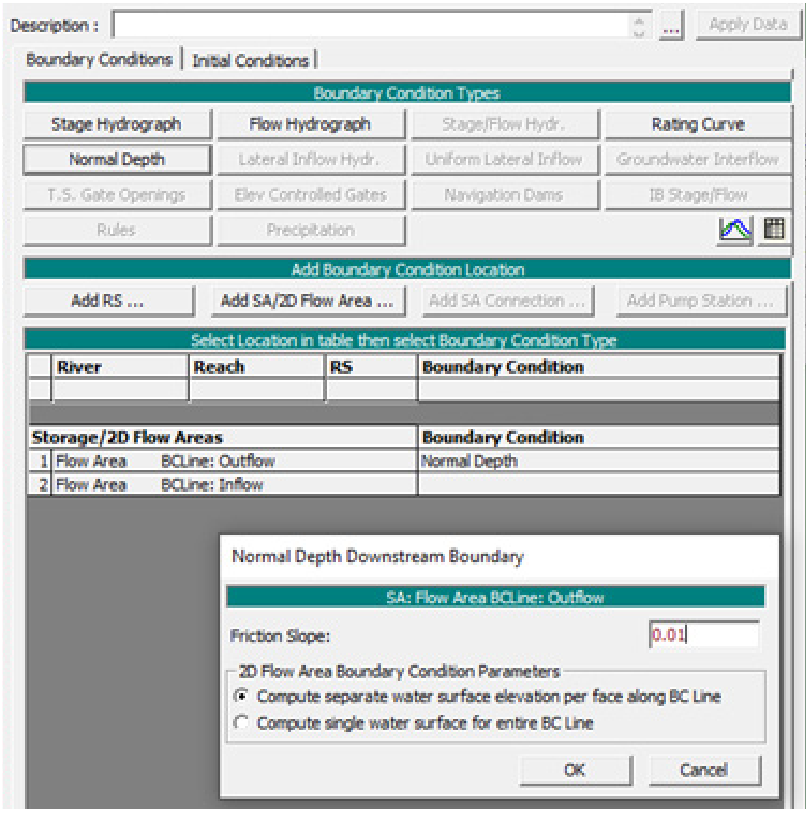


Unsteady Flow Data Preparation

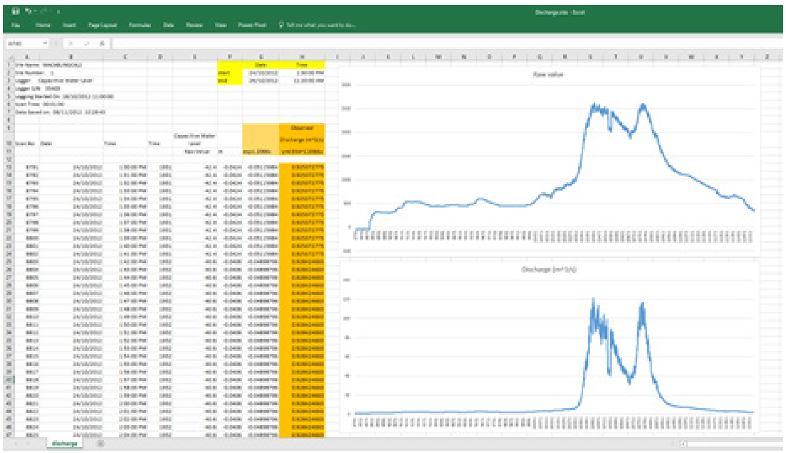
a Click the Edit tab > click Unsteady Flow Data



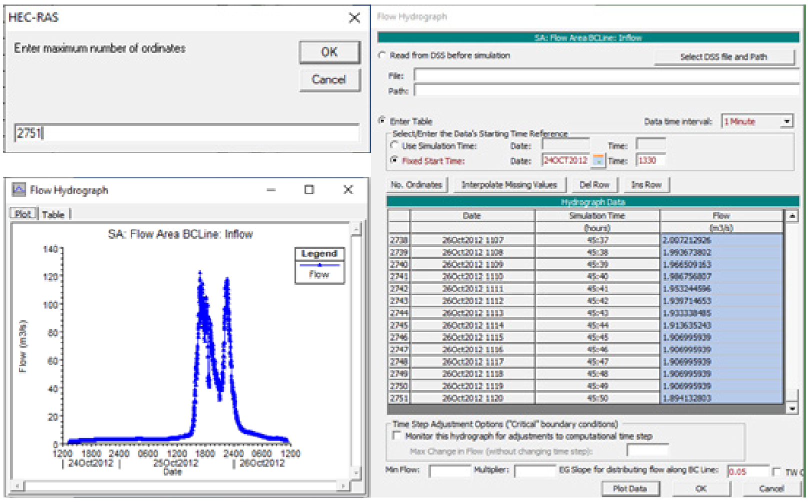
b Under the Boundary Condition column, click the blank space in row 1 > click Normal Depth under the Boundary Condition Types section > type 0.01 for the Friction Slope > click OK.



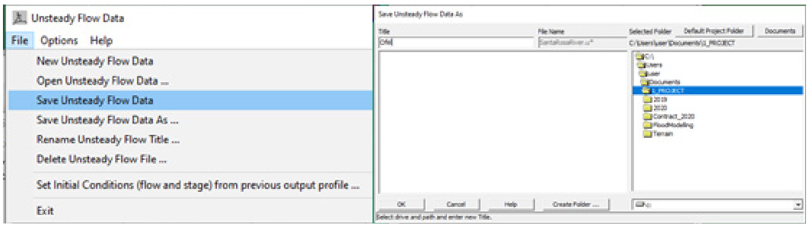
c Open the Discharge excel file under the Data folder. Use the data in the excel file to fill up the Flow Hydrograph windows' information need.



d Under the Boundary Condition column in the Unsteady Flow Data window, click the blank space in row 2 > click Flow Hydrograph under the Boundary Condition Types section > input 1 minute for the Data time interval > select Fixed Start Time then input Date: October 24, 2012 and Time: 1330 > click No. Ordinates tab > type 2751 > click OK > copy the Observed Discharge values in the excel file the paste it in the Flow column in the Flow hydrograph window > input 0.05 in as the EG Slope for distributing flow along BC Line > click Plot Data to check the hydrograph > click OK.

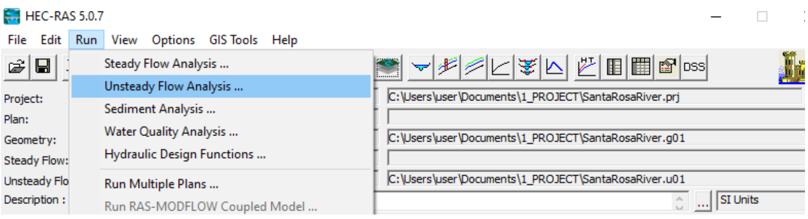


e Click File tab under in the Unsteady Flow Data window > click Save Unsteady Flow Data > type Ofel as the Title of the Unsteady Flow Data > click OK.

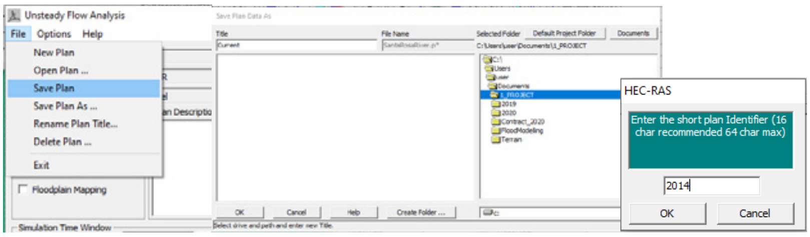


Unsteady Flow Analysis

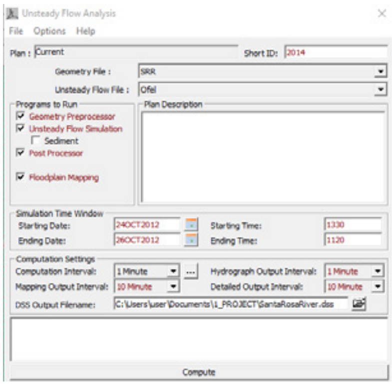
a Click the Run tab > click Unsteady Flow Analysis

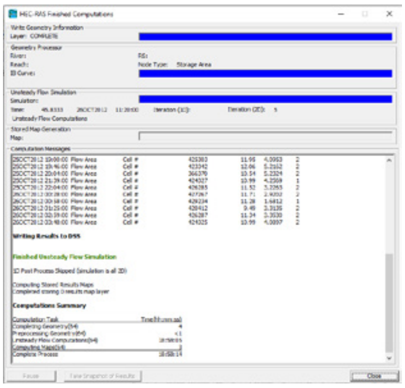


b Click the File tab in the Unsteady Flow Analysis window > click Save Plan > type Current as Title of the plan > type 2014 as short ID > click OK.



c Tick all (except sediment) under Programs to Run section > input starting date and time: October 24, 2012, 1330 > input starting date and time: October 26, 2012, 1120 > select 1 Minute for both Computational Interval and hydrograph Output Interval > select 10 Minutes for both Mapping Output Interval and Detailed Output Interval > click File tab > click Save Plan > click Compute.

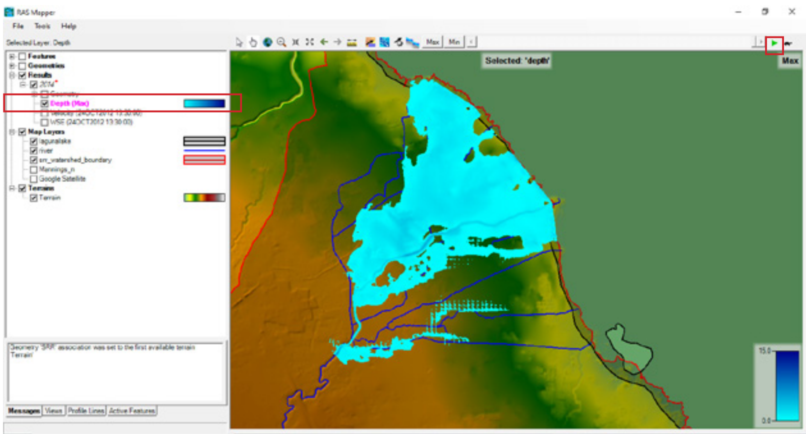




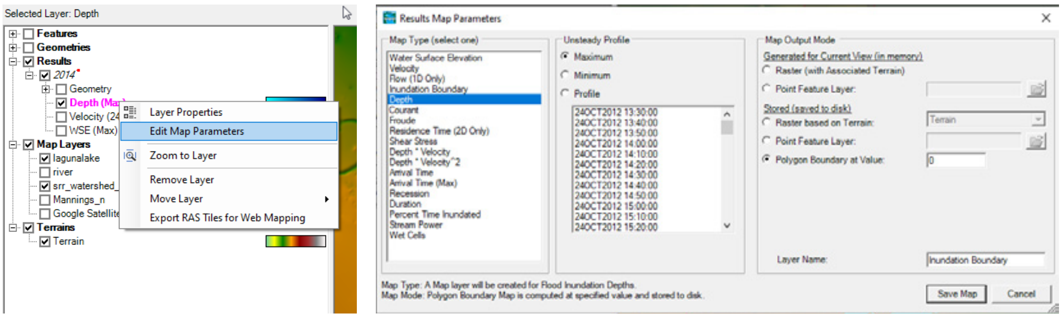
Wait to finish the computation > congratulations if you see the three blue bars > click Close.

View and Export Results in RAS Mapper

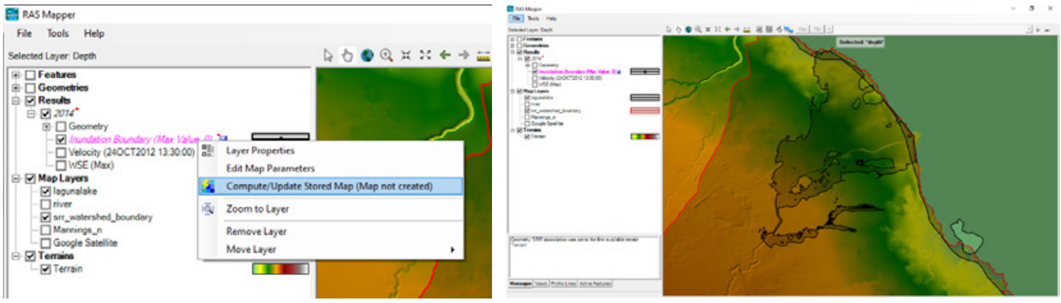
a Open RAS Mapper > view the Depth in TOC > click the Play icon to see the flood simulation.



b Right click Depth layer > click Edit Map Parameters > tick Maximum for the Unsteady Profile and Polygon Boundary at Value under the Map Output Mode section > click Save Map.

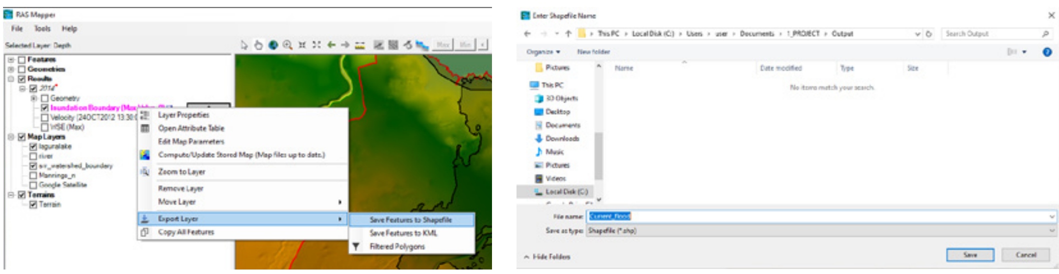


c Right click Inundation Boundary in the TOC > click Compute/Update Stored Map (Map not created).



See that the maximum flood extent boundary has been created.

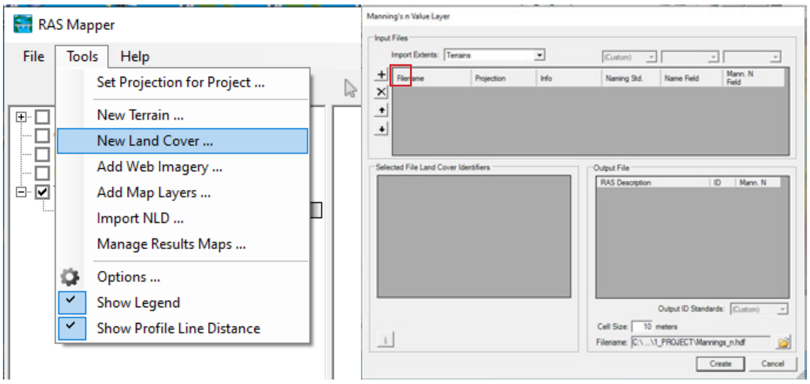
d Export result as Shapefile. Right click Inundation Boundary in the TOC > click Export Layer > click Save Features to Shapefile > navigate to Output folder to save the file.



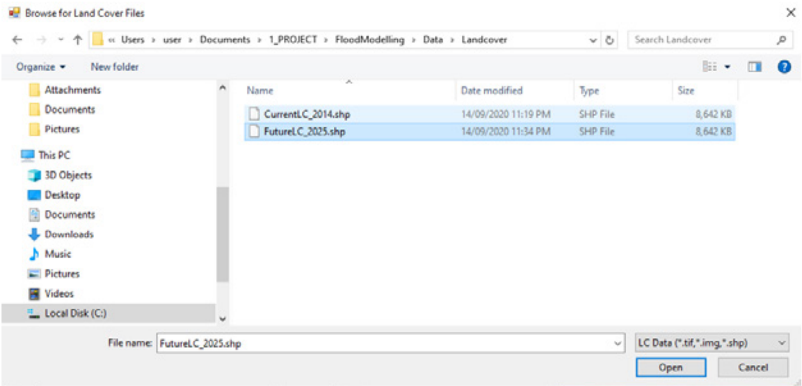
Run the Simulation for Future Landcover

a Repeat the process in adding New Land Cover data but this time, use the FutureLC_2025.shp.

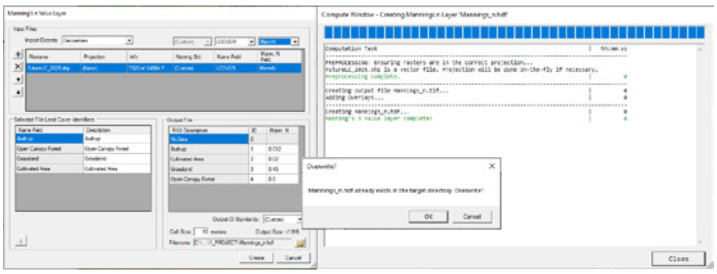
Under the Tools tab of RAS Mapper, click New Land Cover... > click the '+' sign to add the future land cover layer.

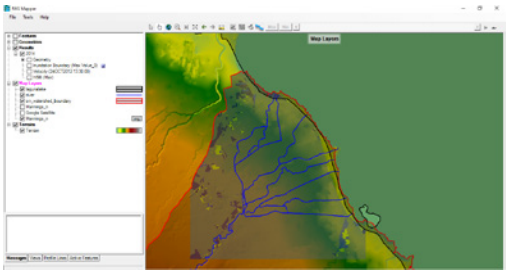


b Navigate to the Data folder then click FutureLC_2025.shp > click Open.



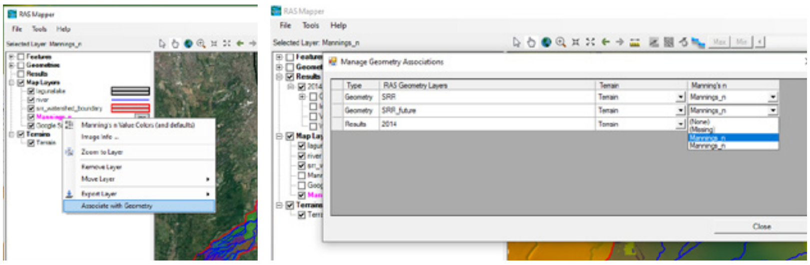
c Select LCOVER and MannN columns in the provided space > click OK for the Overwrite window > click Create > click Close.



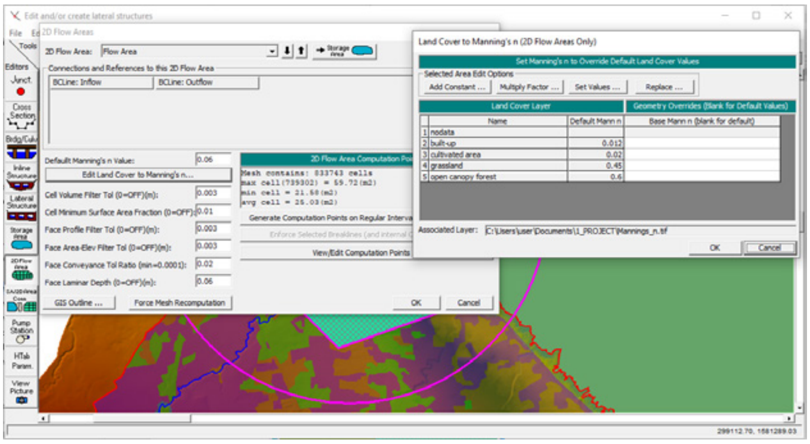


See that a new map layer, Mannings_n is now on the TOC.

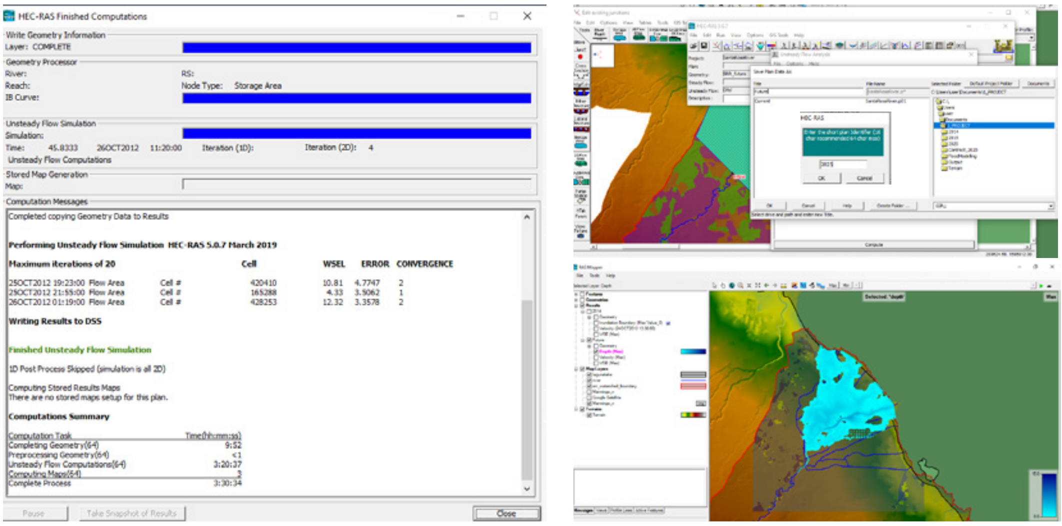
d Open RAS Mapper window. Right click Mannings_n > click Associate with Geometry > click OK > select Mannings_n in the Manage Geometry Association window > click Close.



e Go to Geometric Data – SRR window. Click Edit 2D Flow Areas > click Edit Land Cover to Manning's n... > click OK.



f Create a new plan under the Unsteady Flow Analysis. Name the plan Future with short ID: 2025. Run the simulation and repeat the process of viewing the results in RAS Mapper and exporting results in shapefile. Name the ouput shapefile as Future_flood.



Module 3: Flood Extent Comparison using QGIS

Objectives

The objective of this module is to compare the flood extent of the two land cover scenarios. Specifically, this module discusses how:

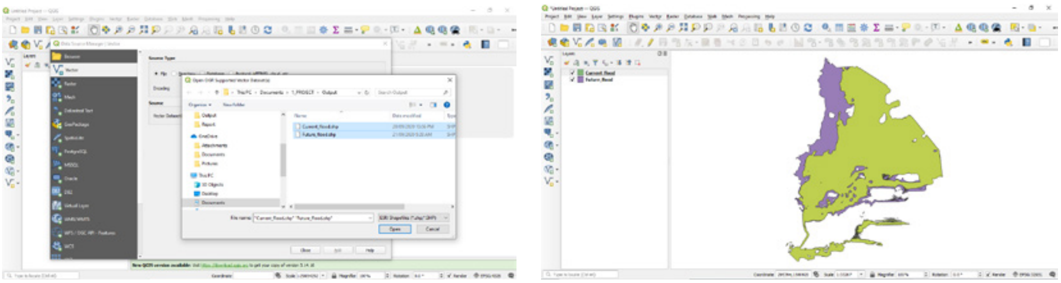
1. To compute the area in hectares of the two flood extents;
2. To stylize the two flood extents; and
3. To overlay the two flood extent layers in preparation for map lay-out.

Materials

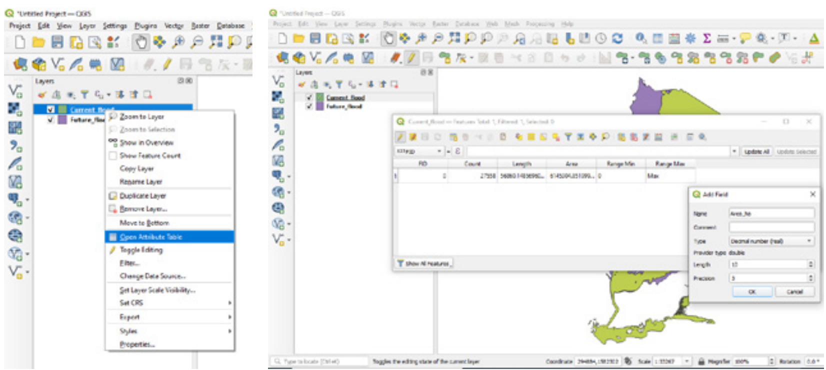
1. QGIS version 3.14
2. QuickMapServices plugin
3. Shapefiles (Watershed boundary, river polylines, and flood extent boundaries)

Flood Area Computation

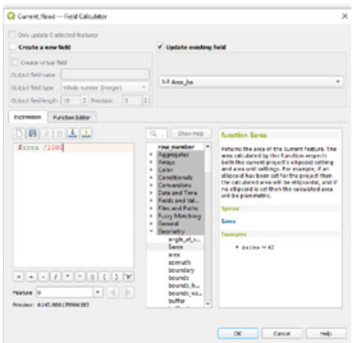
a Open QGIS > click Add Vector Layers > navigate to the Output folder > select both current and future flood extent shapefiles > click Open > click Add > click Close.



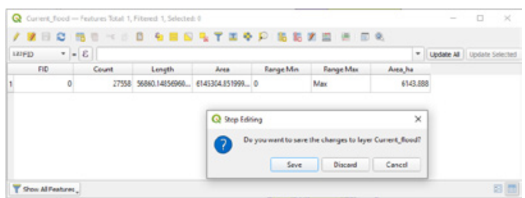
b Right click the Current Flood layer in the TOC > click Open Attribute Table > click the Toggle editing mode icon > click New field > type Area_ha for the Name > select Decimal number (real) for the Type > click OK.



c Click Open field calculator > tick Update existing field > choose Area_ha > find Geometry, double click on $Area then type / 1000 > click OK.

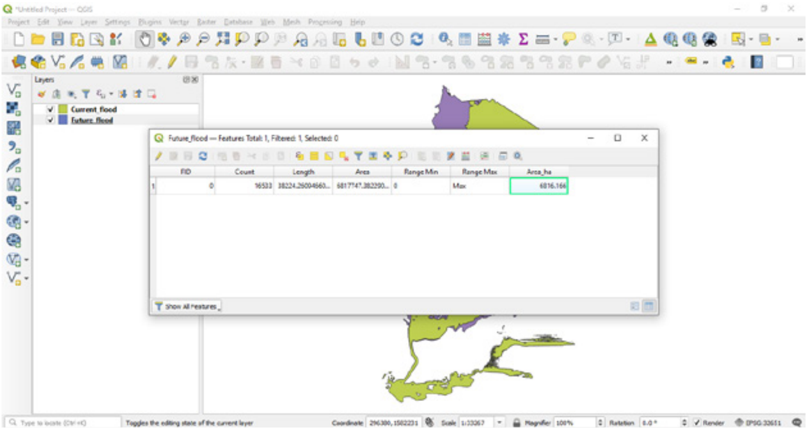


The Area of the Current_flood shapefile is 6,143.89 hectares. Click Toggle editing mode icon to stop editing > click Save.



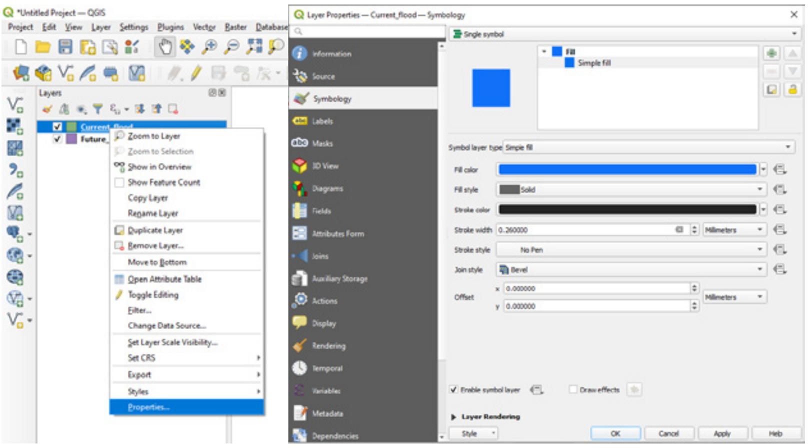
d Do the same process in number 1 for the Future Flood layer.

The Area of the Current_flood shapefile is 6,816.17 hectares.

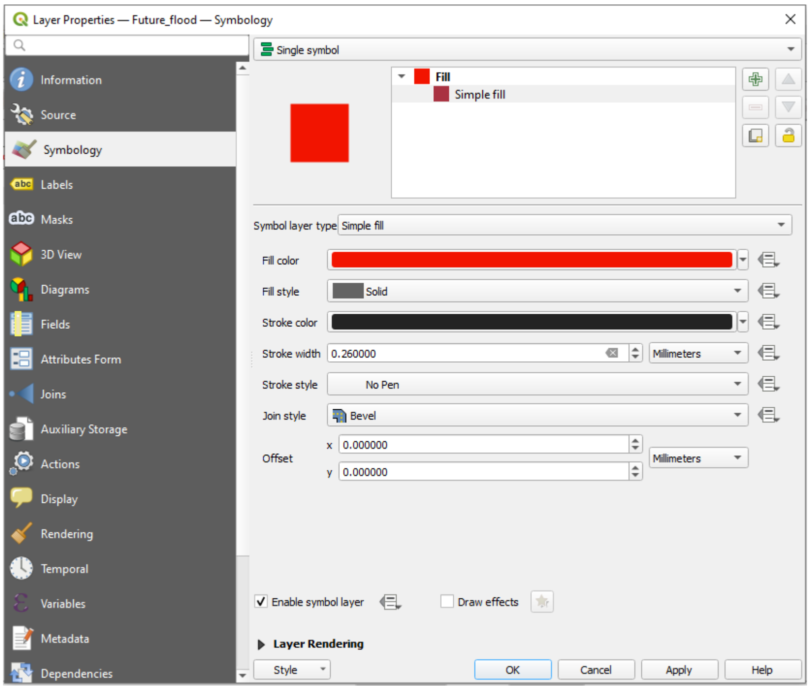


Stylizing the Layers

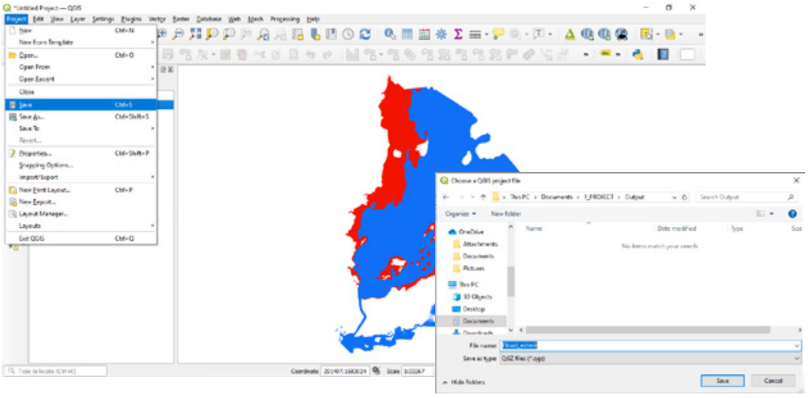
a Right click the Current Flood layer in the TOC > click Properties... > click Symbology tab > click Simple fill > click the color bar in front of Fill color and change it to Blue using the color wheel > click OK >under the stroke style, select No Pen > click OK.



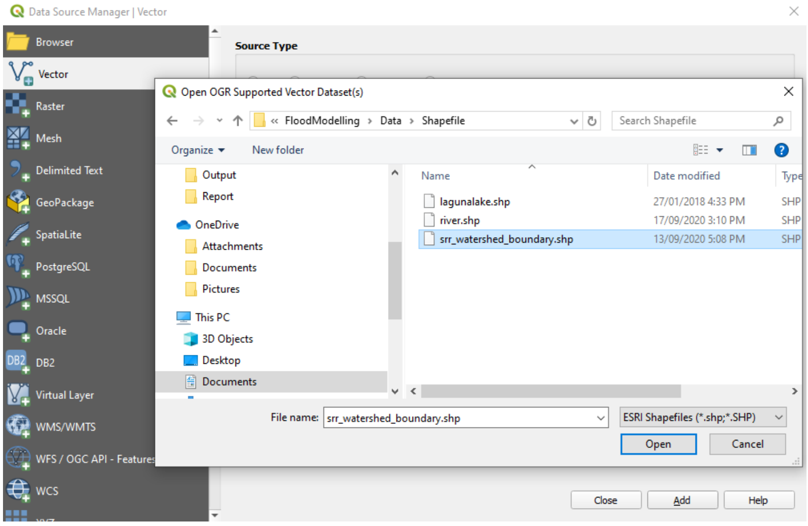
b Do the same process in number 2 for the Future Flood layer. This time choose color Red for the Fill color section.



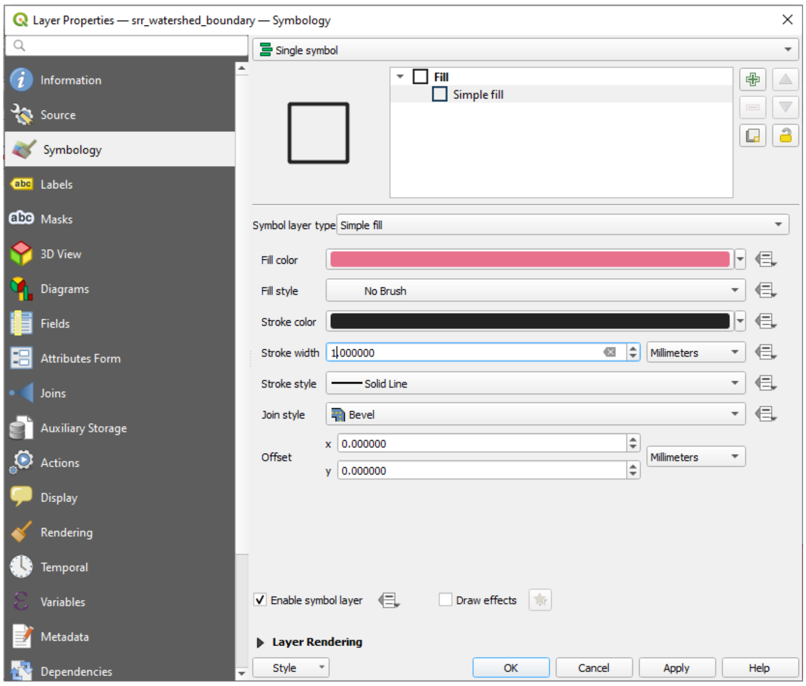
c Save the project. Go to File tab > click Save > navigate to Output folder > type Flood_extent for the File name > click Save.



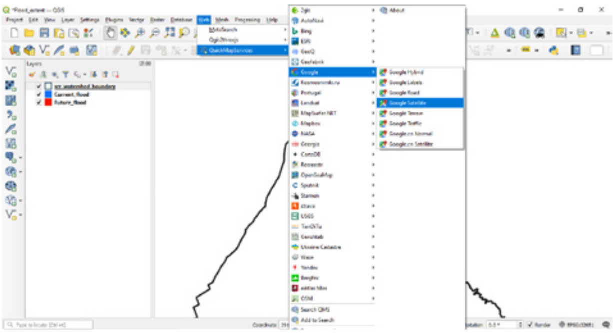
d Load watershed boundary layer. Click Add Vector Layers > navigate to the Data folder > select srr_watershed_boundary.shp > click Open > click Add > click Close.

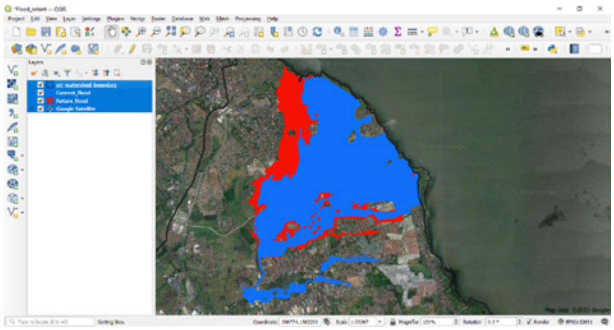


e Right click the river layer in the TOC > click Properties... > click Symbology tab > click Simple fill > under the Fill style, select No Brush > under the stroke color, choose Black color from the color wheel > click OK > under Stroke width, input 1 > click OK.



f Add Google satellite image. Click Web > QuickMapServices > Google > Google Satellite. After the Google satelite is loaded, arrange the layers in the TOC in order from the top to bottom: srr_watershed_boundary, Current_flood, Future_flood, and Google Satellite.





References

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Bragais, M. A., Johnson, B. A., Onishi, A., Endo, I., & Damasa B. Magcale-Macandog. (2017a). Flood extent of different land-use scenarios under event-based precipitation in Silang-Sta. Rosa subwatershed, Philippines. Hayama, Japan: Institute for Global Environmental Strategies.

Endo, I., Johson, B., Kojima, S., Chiba, Y., Nakata, M., Bragais, M., Macandog, P. B. (2015). Making land-use climate sensitive: A pilot to integrate climate change adaptation and mitigation. Hayama, Japan: Institute for Global Environmental Strategies.

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https://www.hec.usace.army.mil/software/hec-ras/

https://www.qgis.org/en/site/

https://www.gadm.org/

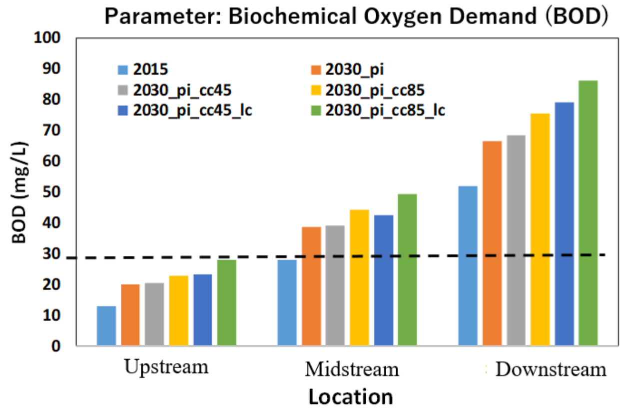
Johnson, B. A., Endo, I., Magcale-Macandog, D. B., Bragais, M., & Macandog, P. B. M. (2015). Recent land cover change in the Silang-Sta. Rosa sub-watershed of the Philippines, and implications for flood risk. Hayama, Japan: Institute for Global Environmental Strategies.

Laguna Lake Development Authority (LLDA)

National Mapping and Resources Information Authority (NAMRIA)

Chapter 5: Water quality impact assessment

Pankaj Kumar
Brian A. Johnson



Legend
2015- current status,
2030_pi – Scenario with population increase,
2030_pi_cc45 – Scenario with population increase and moderate climate change (RCP 4.5),
2030_pi_cc85 – Scenario with population growth and extreme climate change (extreme RCP 8.5),
2030_pi_cc45_lc – Scenario with population increase, climate change (moderate RCP 4.5) and land-use change,
2030_pi_cc45_lc – Scenario with population increase, climate change (extreme RCP 8.5) and land-use change

Overview of this chapter

Surface water quality is closely linked to human activities (e.g. water demand, wastewater discharge/runoff, and land-use/land-management) as well as local climate conditions. Thus, changes in population, water treatment infrastructure, land-use, and climate all result in modification of the water quality of nearby rivers/lakes/coastal waters.

This Chapter will show you how to simulate the future water quality of a watershed using the "Water Evaluation and Planning System" (WEAP) software package, which is free for users in developing countries. You will learn to conduct several different types of scenarios, to understand and model the impacts of population growth, infrastructure development, land-use change, and climate change on water quality.

After completing the chapter, you will be able to:

This chapter will introduce you to GCMs and downscaling, and show you how to access downscaled climate data.

- Use WEAP software to estimate the water quality of a watershed;
- Integrate future population projections, infrastructure-related information, land-use, and climate information to develop different scenarios of the future water quality.

Main concepts

Improving urban water environment is of great significance, considering the importance of clean water for biodiversity and ecosystem services. Clean water is needed to ensure healthy fish stocks, and that water is clean enough for recreational activities, bathing, tourism, cultural and religious activities, etc. To analyze the sustainability of future urban development with regards to water resources, various scientific tools can be used, e.g. to forecast the future state of urban water environment under different scenarios. These tools are useful in that their outputs provide science-based evidence for decision-making, and the involvement of local stakeholders in the process can improve the modeling results (e.g. by better accounting for the local context) as well as build the capacities of the stakeholders involved in water management.

This chapter presents the Water Evaluation and Planning (WEAP) took, a computer modeling tool that takes into account hydrological and water quality components to analyze/simulate the current/future water quality. WEAP is widely used as a decision support tool for integrated water resources management and planning. The model allows for the estimation of rainfall runoff and pollutant transport from a catchment to nearby water bodies. WEAP can support environmental master planning functionalities by accounting for wastewater generation and treatment, and includes a catchment module for rainfall-runoff simulation (an essential input parameter for water quality modeling. Other benefits of WEAP are that it is not data intensive, and that it is freely available to people in developing countries.

In this chapter, we will show how the WEAP model can be used to simulate future total water demand and water quality variables (targeting the year 2030) in the Santa Rosa watershed of the Philippines, and to assess different management policies.

Model set-up

To run the WEAP tool, first vector or raster file of administrative boundary of the study area and river map is imported into the software. After tracing the river on the top of the administrative map, we create our problem domain. The whole problem domain (and its different components) is divided into several sub-catchments, which are further subdivided into different sub-basins, to consider influent locations of river and its major tributaries being represented by respective WEAP nodes. Other major considerations are many demand sites (number usually depend on lower administrative unit of study area by which data is available) and wastewater treatment plant to accurately represent the current situation of the study area. Here, demand sites denote domestic (population) defined with their attributes explaining water consumption and wastewater discharge in concerned river. As a countermeasure, Wastewater treatment plants (WWTPs) are considered as pollution handling facilities with design specifications including total capacity and removal efficiencies of pollutants. In this case, an upflow anaerobic sludge blanket reactor (USAB) type of wastewater treatment plant with its pollutant removal efficiency is considered in the modeling. The daily volume of domestic wastewater generation in this area of the Philippines ranges from around 100-180 liters per day per capita, however because of non-availability of precise data in some of the areas it was fixed at 130 liters of average daily consumption per capita. Apart of this, we do need to plot river gauge stations, ground water supply and finally different types of links (return flow, transmission flow, and runoff/infiltration) to finalize model set-up.

Scenario analysis is carried out by defining a time horizon for which alternative wastewater generation and management options are explored, which is 2030 in this case. The business as usual condition is represented by a reference scenario with selection of all the existing elements as currently active. Consequently, new WWTPs (hypothetically considered as countermeasures) are modeled as scenarios representing deviations from the current conditions (reference scenario). The baseline year under the current reference scenario for all study areas also varies based on the past data availabilities.

Model performance evaluation

Before doing future scenario analysis, performance of the WEAP simulation should be assessed based on the association between the observed and simulated values of the hydrological and water quality parameters. For this Chapter's case study, hydrology module parameters (mainly effective precipitation and runoff/infiltration) were adjusted during simulation in order to reproduce the observed monthly stream flows for the period of certain year for hydrology module validation. Whereas the water quality simulation part is validated by comparing the simulated and observed concentration of water quality concentrations at some observation points. Selection of the locations and times in the case presented in this Chapter were made on the basis of consistent availability of observed water quality data. Once satisfactory correlation between observed and simulated values were confirmed statistically, future simulation for both water quality and hydrological parameters were initiated.

Parameter	Initial Value	Step
Effective precipitation	100%	±0.5%
Runoff/infiltration ratio	50/50	±5/5
Household discharged water quality parameters concentrations both at the observation site and river head	X mg/L or CFU/100ml	±0.5%

Tutorial

Risk assessment (For water quality component)

WEAP (Water Evaluation and Planning) model is used based on the following benefits:

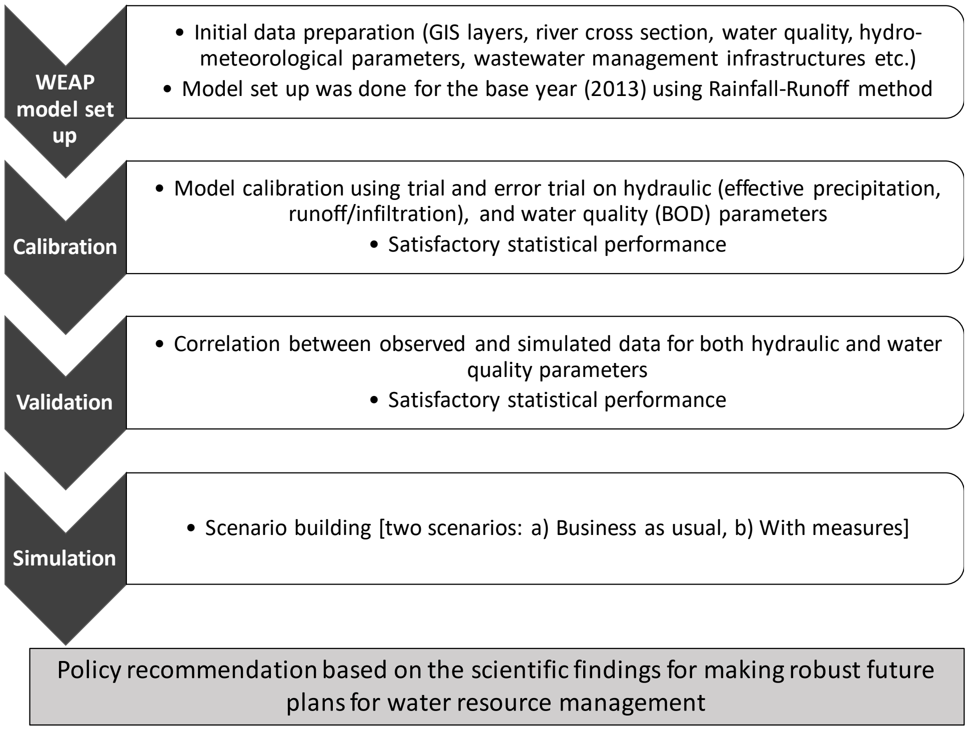
- Freely available for developing countries
- A highly flexible hydrologic-water quality model
- WEAP can model large number of pollutants
- GIS-based, graphical drag & drop interface
- Scenario management capabilities

Expected outcome

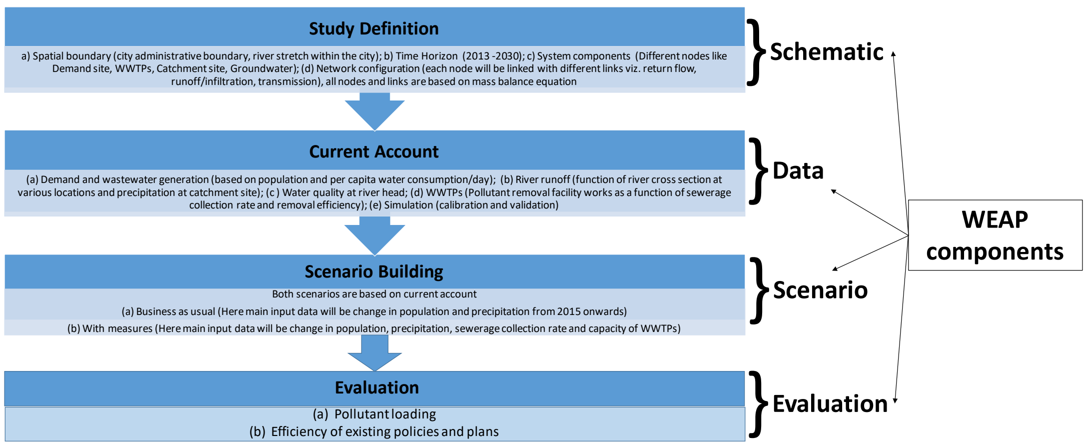
1. With scenario based simulation, we will be able to predict what will be the future situation of the water environment
2. It will also help to identify what are the suitable mitigation/adaptation measures for improving this water environment and what is the best strategic location to establish these infrastructures as countermeasures

The WEAP model framework and model structure are shown in the two images below.

Looking in to the flowchart of the model framework, it has four major components viz. WEAP model set up (schematic diagram and data input), calibration, validation and finally simulation. Structure of the model consists of four components e.g. schematic diagram, data input, scenario analysis and finally evaluation of scientific data for policy formulation (providing credible scientific evidence for policy formulation).



Flowchart showing work framework.



Flowchart showing model structure.

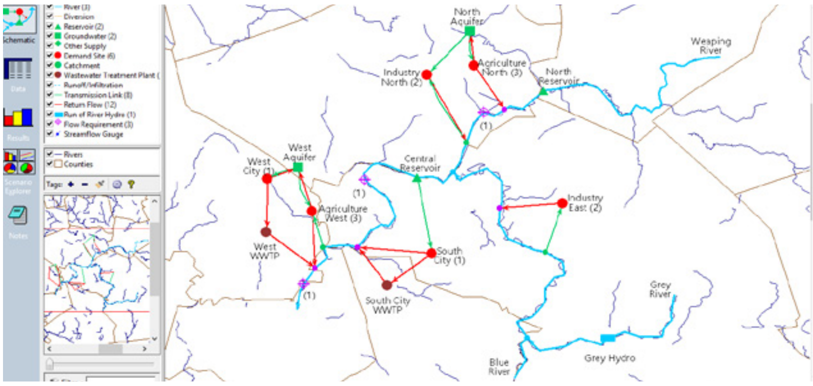
Steps needed prior to proceeding with this WEAP tutorial

a Before working with WEAP software, download and register it from http://www.weap21.org/. After that, you will need to request and procure the free license to proceed.

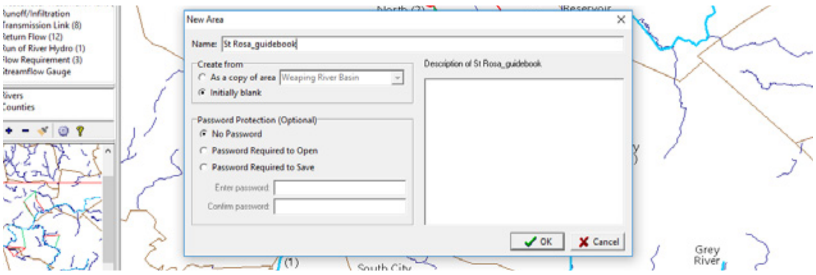
b Copy the "WEAP_training_St_Rosa" folder, containing the data necessary for this tutorial. Now, you are ready to move on to Step 1 of this tutorial

Step 1. Establish a New, Blank Area.

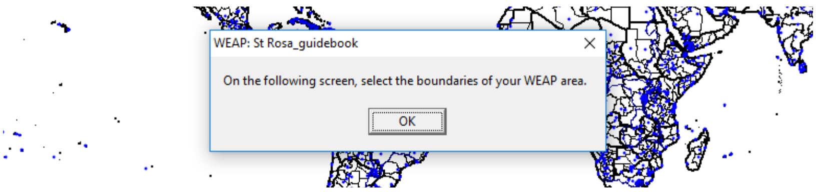
a Open WEAP for the first time. A project area called "Weaping River Basin" will appear. Click on the Area -> Create Area menu option to make a new, blank area.



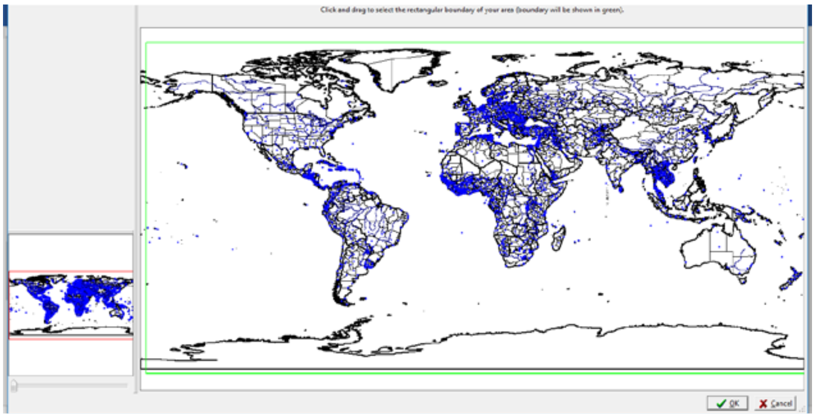
d A window, as shown below, will appear in which you should click on the "Initially Blank" option. In the next steps, you will be defining this area for a specific geographic area of the world - so you can name the area based on this selection if you like (e.g., St Rosa Area).



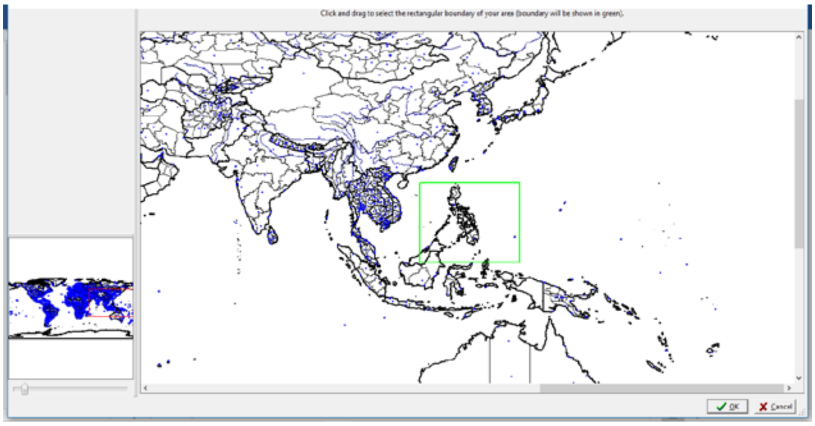
c After clicking "OK" you will be prompted to save changes to the Santa Rosa River Basin. After clicking yes, you will get the following screen:



d Click "OK" again. In the next screen, you will select the geographic area for your project from the world map that appears. Use your cursor to draw a rectangle around the area that your project will represent. The boundaries will appear as a green rectangle as shown below.



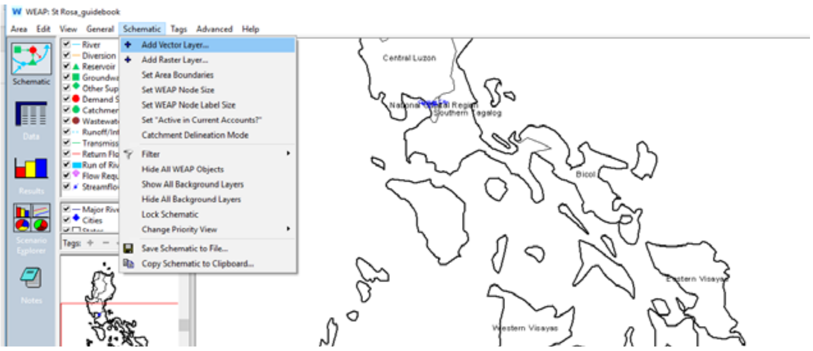
e You can then use the slider bar on the lower left of the window to zoom into this selected area.



f You can redraw you green rectangle to best capture the area you want in this view. Click on "OK" when you are satisfied with your area boundaries. Note that you can modify these boundaries later by choosing "Set Area Boundaries" on the pull-down menu under Schematic on the top menu bar.

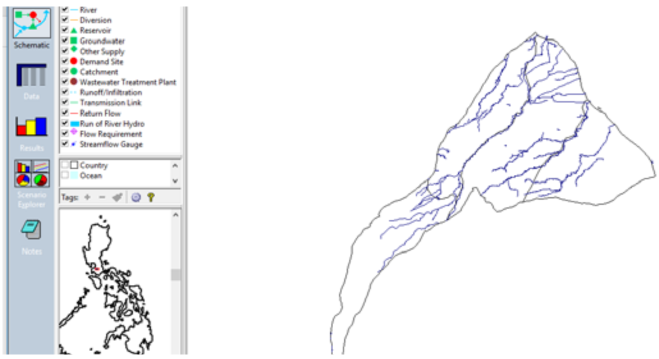
Step 2. Add a GIS layer to the Area

a You can add GIS-based Raster and Vector maps to your project area - these maps can help you to orient and construct your system and refine area boundaries. To add a Raster or Vector layer, right click in the middle window to the left of the Schematic and select "Add a Raster Layer" or "Add a Vector Layer."



b A window will appear, in which you can navigate to the "WEAP_training_St_Rosa" folder. Add the "SantaRosaSubwatershed.shp" file in this folder. After adding the file it will look like as follows:

c Next, add the "waterwaysSR.shp" file, which contains the river network in the study area. And now toggle off the other background layers like country, cities, state as shown in the figure below



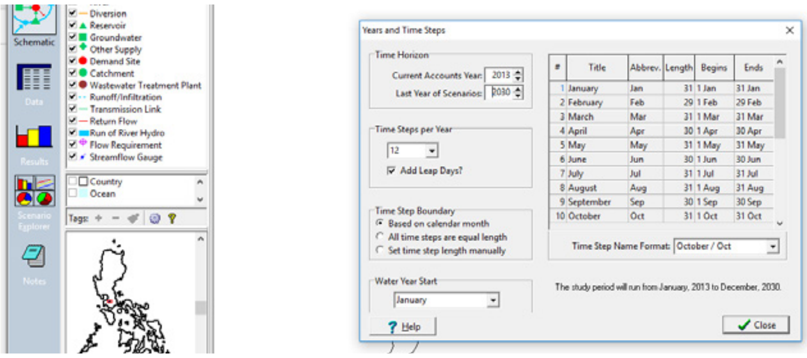
Step 3. Setting General Parameters

Now we're going to proceed with learning how to navigate through WEAP and its functionalities.

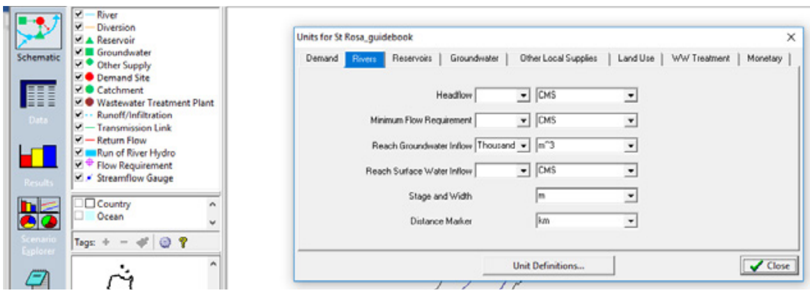
a Click "General" from menu and using drop down menu select different options and set the different parameters like to set Years and Time Steps.

b Set the Current Accounts Year to 2013 and the Last Year of Scenarios to 2030. Set the Time Steps per year to 12. Set the Time Step Boundary to "Based on calendar month" and starting in January (see below) Keep the default (SI units) for now.

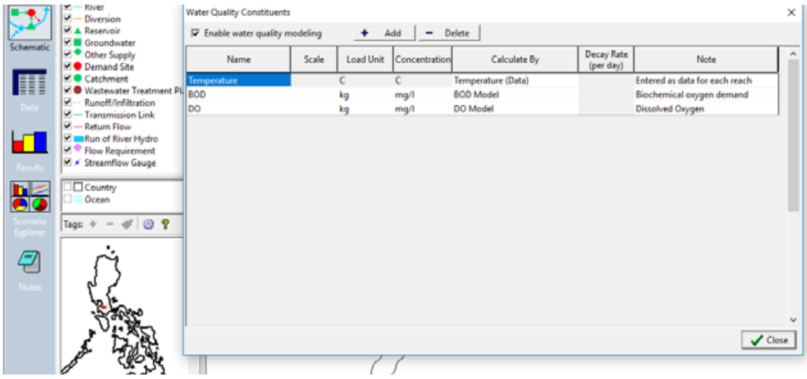
Here the year 2013 will serve as the "Current Accounts" year for this project. The Current Accounts year is chosen to serve as the base year for the model, and all system information (e.g., demand, supply data) is input into the Current Accounts. The Current Accounts is the dataset from which scenarios are built. Scenarios explore possible changes to the system in future years after the Current Accounts year. A default scenario, the "Reference Scenario" carries forward the Current Accounts data into the entire project period specified (here, 2013 to 2030) and serves as a point of comparison for other scenarios in which changes may be made to the system data.



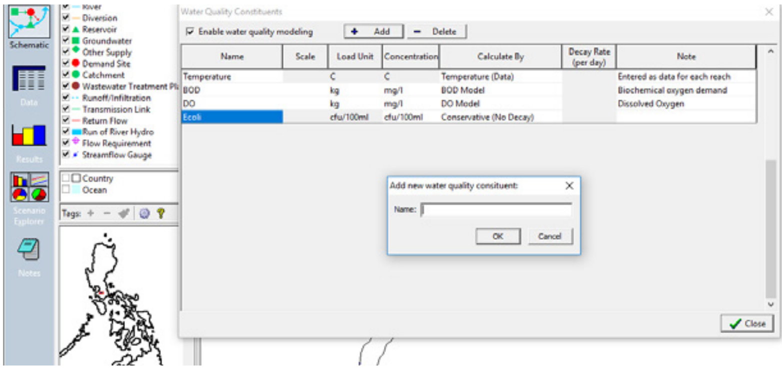
c Similarly, under "General", the units also be set.



d Next if we want to do the simulation of water quality parameters, we need to select general—water quality parameters and must click enable water quality modeling. By default, WEAP will simulate temperature, BOD and DO.

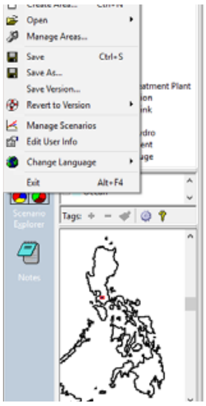


e However if we need to add other parameter, we can do that after click add button and adjust units as our observed data as shown below.



Step 4. Save a version of your Area

a Select "Save Version" under the "Area" menu. After saving all the files will be saved in folder named as WEAP area where your set up file are there.



Step 5. Entering Elements into the Schematic

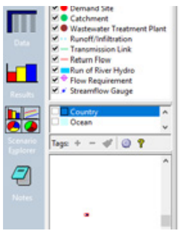
First, we will draw a River

a Click on the “River” symbol in the Element window and hold the click as you drag the symbol over to the map. Release the click when you have positioned the cursor over the upper left starting point of the main section of the river. Move the cursor, and you will notice a line being generated from that starting point.

Important Note- The direction of drawing matters: the first point you draw will be the head of the river from where water will flow. You can edit the river course later on by simply clicking-moving any part of the river to create a new point, or right-clicking any point to delete it.

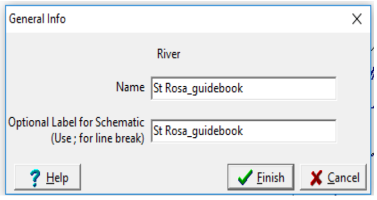
In the next several steps, you will draw the main river, drawing from the upstream (upper left) to the downstream (lower right) area, clicking once to end each segment that you draw. You can follow the line of the river as closely as you like, or you can draw a less detailed representation (below). Note though, that how closely you follow the actual course of the river will have implications for the performance of certain functionalities in WEAP. For example, if you plan to model water quality parameters along the river, it would be advantageous to construct the river element as closely as possible to the actual river course, because WEAP will need to calculate residence times in the river (a function of reach lengths) to perform water quality simulations. Zooming in on the river (using the zooming bar in the lower schematic window) can help if you want to follow the rivers path more closely. You do not need to draw a river on the branch coming horizontally from the left. You can also adjust the river later if you want to add more detail.

b First deselect country and other information not necessary for the schematic diagram development.

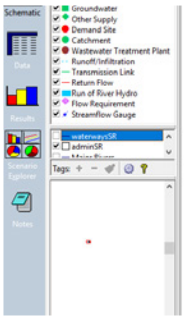


c Click on the symbol river in the element window.

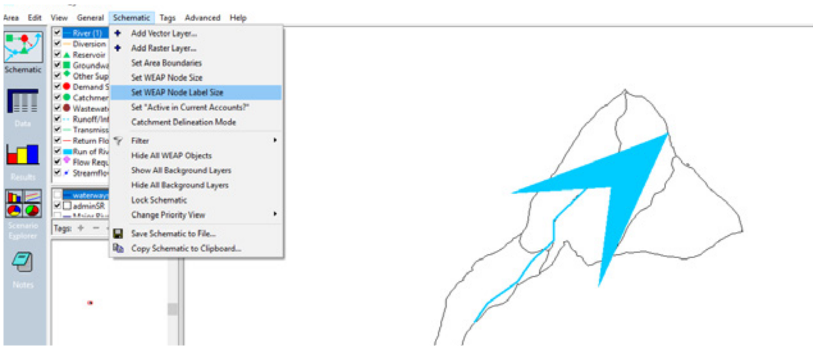
d Please start your drawing from the point which you consider as upstream (around the lower left area shown in the red box below). Try to draw the river as shown in the image below. Once you finish drawing the river, double click to end the drawing. A window will appear ask you to name the drawn river. Put the name you want.



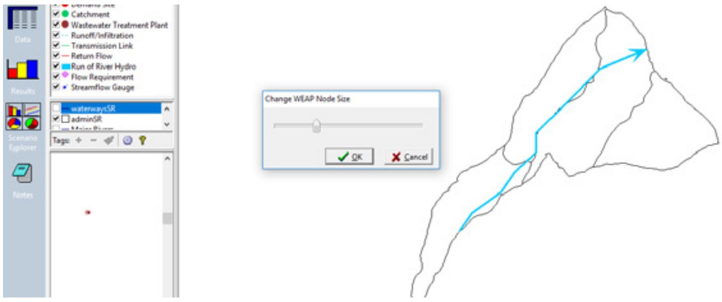
e Now remove background layer of river network from GIS layer we have imported before as shown below.



f Now to adjust the size of river node in compare to the model domain, click onset WEAP node label size as a dropdown menu under schematic tab.

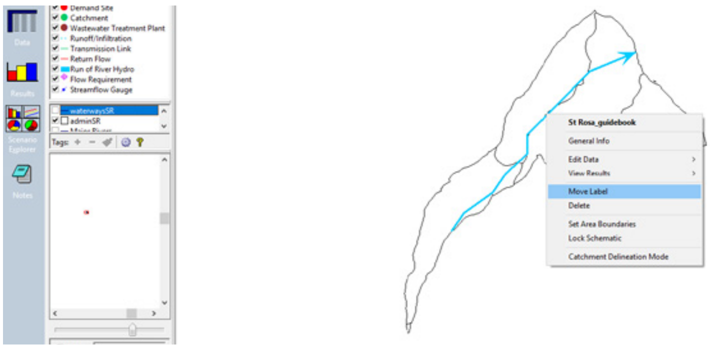


g Adjust the size putting curser on the zooming tool shown below. Once satisfied click OK.

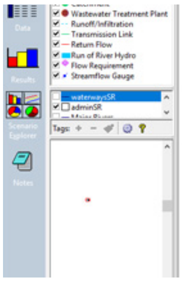


h Now set the label name using Set WEAP Node Label Size under Schematic. Adjust as per your wish.

i As river name is not appearing on the screen, right click and select move label. And with cursor you can move the placement of the label wherever you want.



j Finally it will look like screen shown below.

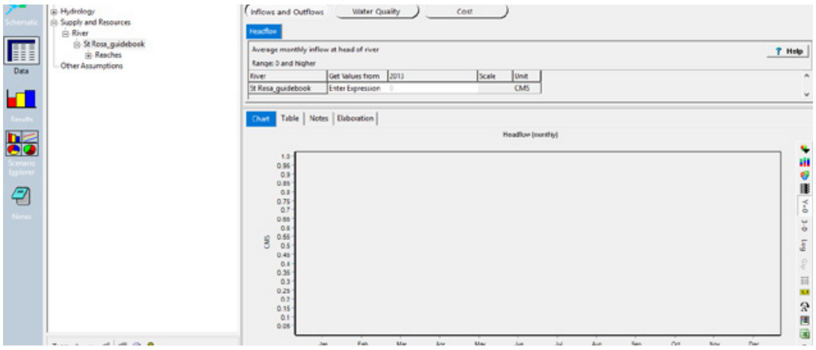


Step 6. Enter Data for the Main River

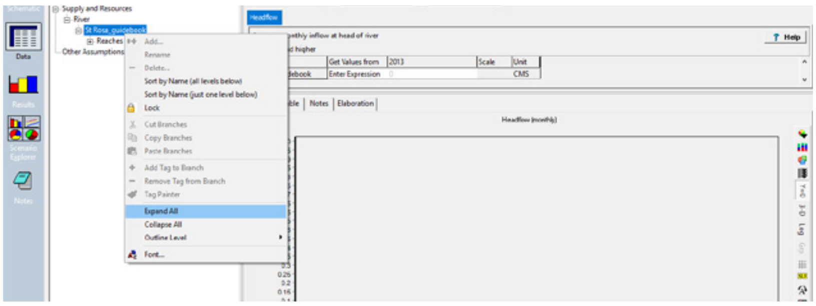
There are two ways to navigate to the data entry section of WEAP to enter data for the Main River. Let's try them.

a Right-click on the Main River and select Edit data and any item in the list.

b Switch to the Data view by clicking on the Data symbol on the left of the main screen. Select: Supply and Resources/ River /Main River in the Data tree. You may have to click on the "plus sign" icon beside the Supply and Resources branch in order to view all of the additional branches below it in the tree.



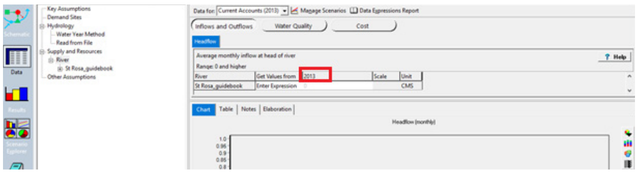
c Alternatively, you can use the Tree pull-down menu and select "Expand All" to view all branches.

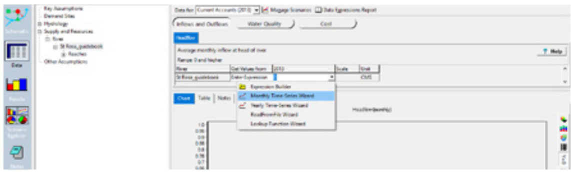


Entering Elements into the Schematic

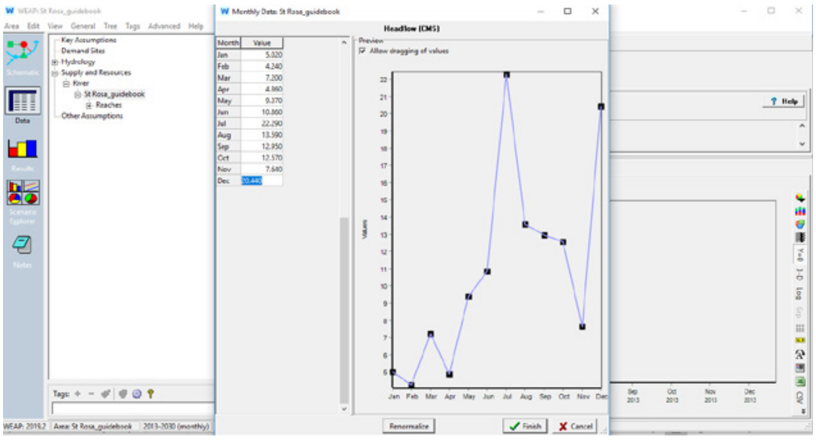
d The “Inflows and Outflows” window should be open - if it isn’t, click on the appropriate button. Click on the “Headflow” tab.

e Click on the area just beneath the bar labeled “2013” in the data input window to view a pull-down menu icon. Select the “Monthly Time-Series Wizard” from the drop--down menu.

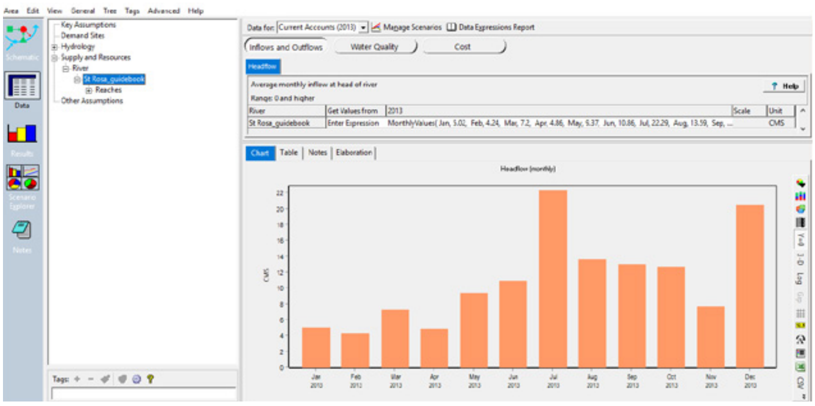




f Use the Monthly Time Series Wizard and enter the following data series:



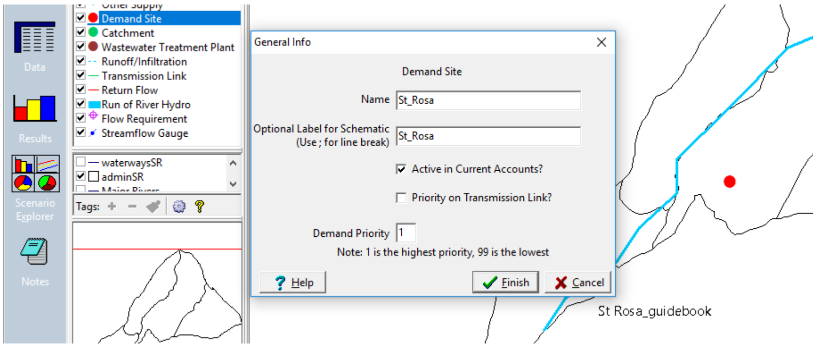
g Note that as you enter each data point, the data is shown graphically also. Do not input or change any other data yet. Push Finish to close the wizard.



Note- WEAP divides up rivers into reaches (segments). Originally your river has only one reach; as you add with-drawal and return points, WEAP will automatically create new reaches.

Step 7. Create an Urban Demand Site and Enter the Related Data

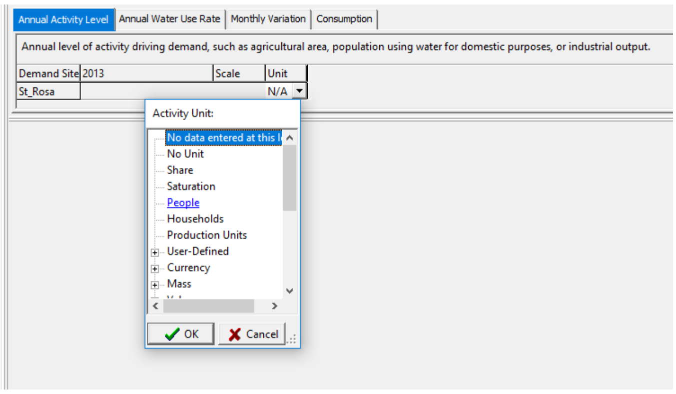
a Creating a demand node is similar to the process you used to create a river. Return to the Schematic view and pull a demand node symbol onto the schematic from the Element window, releasing the click when you have positioned the node on the left bank of the river (facing downstream) inside the administrative boundary of the study area shown in black line. Enter the name of this demand node as “St Rosa” in the dialog box, and set the demand priority to 1.



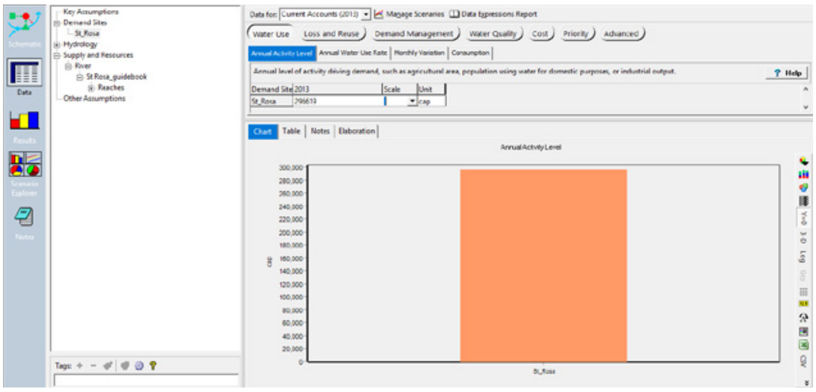
b Right click on the Big City demand site and select “Edit data” and “Annual Activity Level.” This is the alternative way to edit data, rather than clicking on the “Data” view icon on the side bar menu and searching through the data tree.

Note- The Demand Priority represents the level of priority for allocation of constrained resources among multiple demand sites. WEAP will attempt to supply all demand sites with highest Demand Priority, then moving to lower priority sites until all of the demand is met or all of the resources are used, whichever happens first

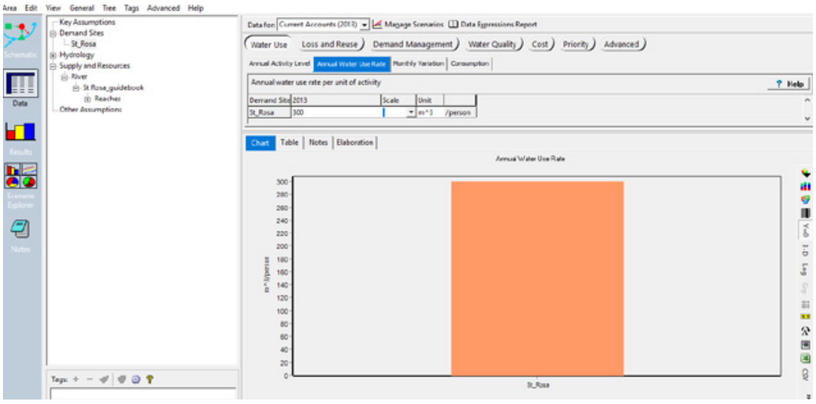
c You must first select the units before entering data. Click on the “N/A” under Unit in the Annual Activity level tab. Pull down the arrow that appears, select “People”, and click “OK.”



d In the space under the field labeled "2000", enter the Annual Activity Level as 296619.

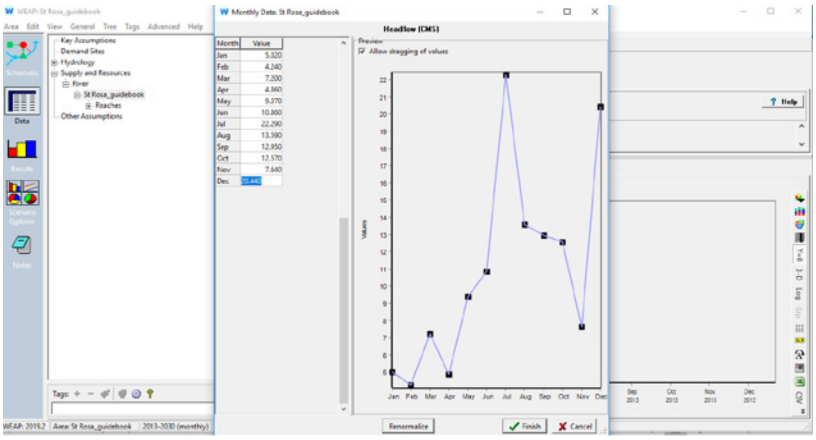


e Next, click on the "Annual Water Use Rate" tab and enter 300 under the year 2013.



> Note- The monthly variation is expressed as a percentage of the yearly value. The values for all of the months have to sum up to 100% over the full year. If you don't specify monthly variation, WEAP will prescribe a monthly variation based on the number of days in each month. We will not edit these values for the city demand, but we will edit them later for the agricultural demand.

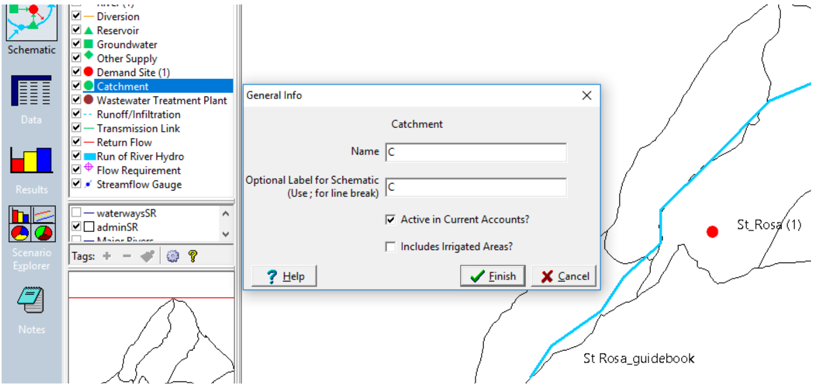
f Finally, click on the "Consumption" tab and enter 15. Note that the units are pre-set to "percent."



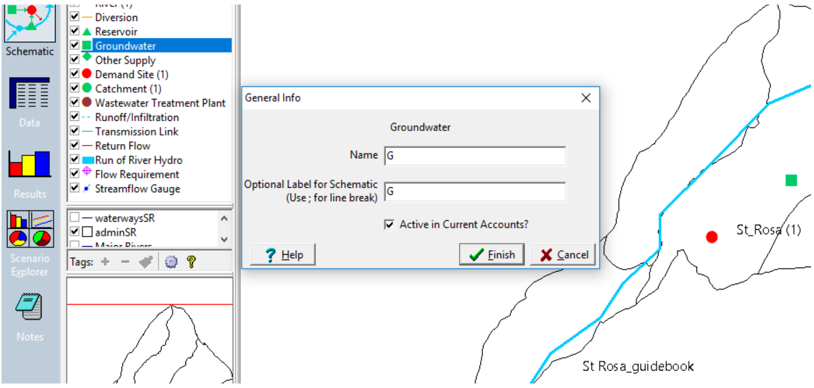
Step 8. Create an Catchment and groundwater supply for the demand site

a Pull the catchment node symbol into the project area and position it on the river head and name it as "C". But during the complex simulation, we can divide whole study area in to different sub-catchments. It will be used to generate river discharge and runoff.

b Tick the box for active in current account.



c Now we add groundwater supply, as we will assume people in the study area consume only groundwater



d Add a wastewater treatment plant and named as WWTP.

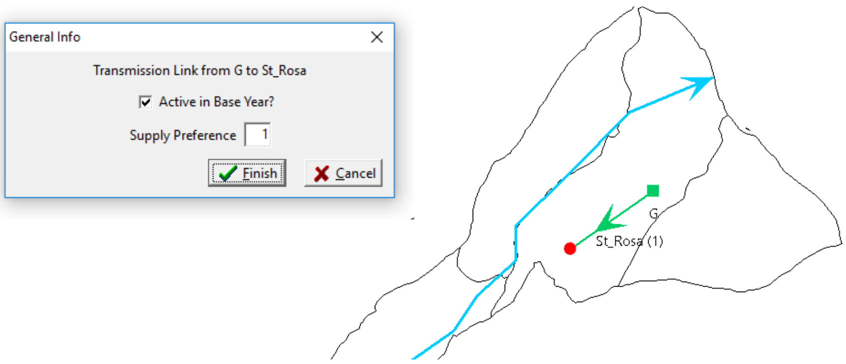
Note - For all nodes we should tick the box active in current account except WWTP. As we will make one scenario with proposed WWTPs.

Step 9. Connect the Demand with a Supply

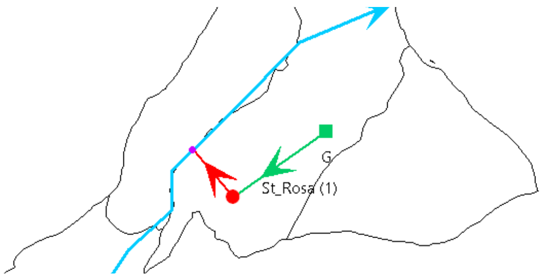
You now need to tell WEAP how demand is satisfied. This is accomplished by connecting a supply resource to each demand site. Return to the Schematic view and create links to connect catchment, groundwater, river and demand sites. Do this by dragging the different links e.g. Transmission Link first to a position on the groundwater, releasing the click, then pulling the link to demand site and double clicking on this demand node.

a Create a Runoff/infiltration link to connect catchment to river

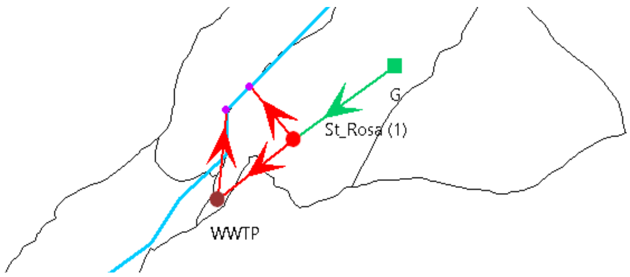
b Create a Transmission link to connect from the groundwater to demand site



c Create a Return flow link to connect demand site to river.



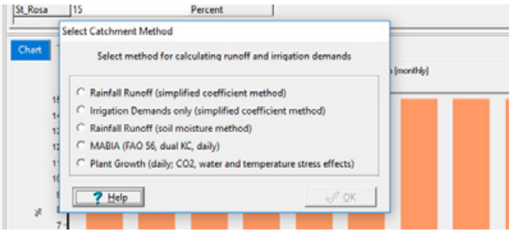
d Create a flow link to connect demand site to WWTP, and a Return flow link to connect WWTP to river.

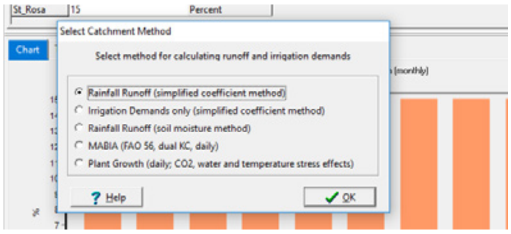


Note- Position of runoff/infiltration link connecting catchment to the river matters a lot. Be aware that the position you will release the click of runoff/infiltration link, will be considered as river head in the model by default.

Step 10. Entering the data

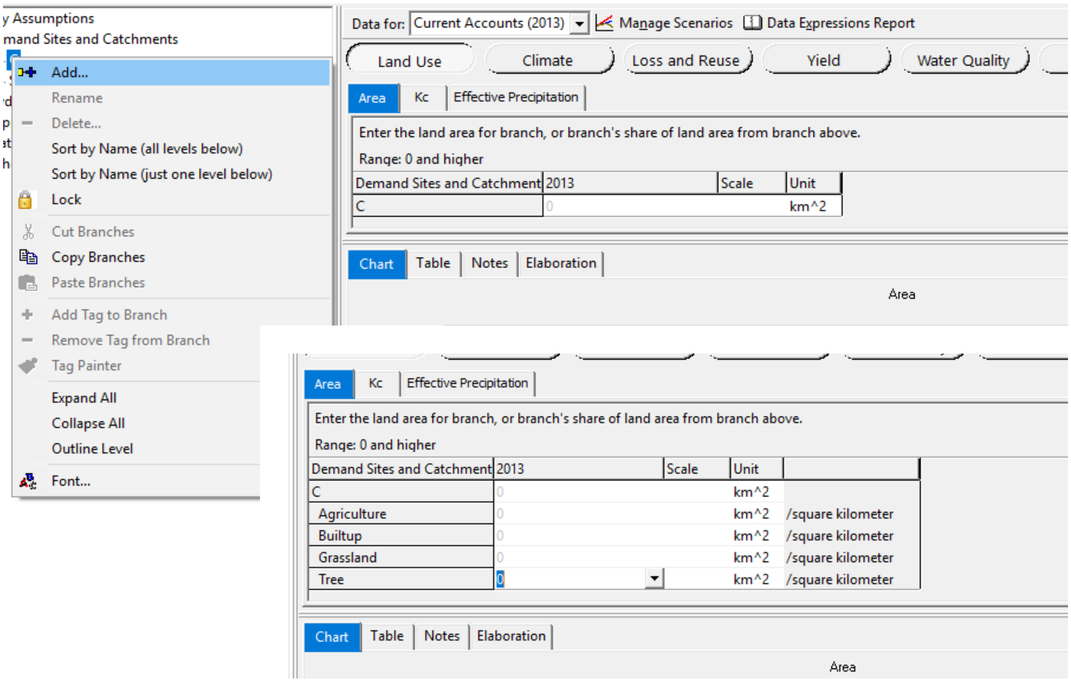
a Select “C” in the assumption tree, first select catchment method. Ideally soil-moisture method is best suitable method to calculate runoff as it divides the aquifer in two layers vadose zone and saturated zone mimicking the real world situation more closely. However number of input data is quite huge. In this case (St Rosa), because of data scarcity, we have selected rainfall-runoff (simplified coefficient method).



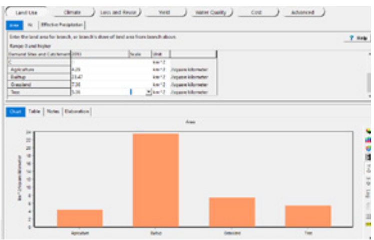


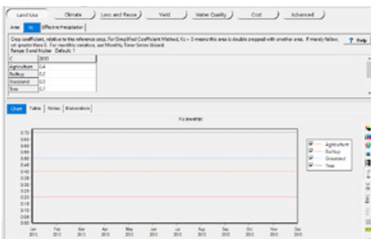
Data for catchment “C”

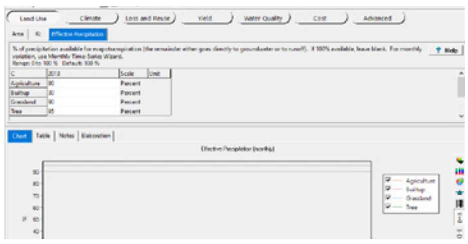
b Now give the values for the area of each land-use/land cover type in the study area. Click data Click C click add and add “Agriculture”, “Builtup”, “Grassland”, and “Tree” land-use/land cover types.



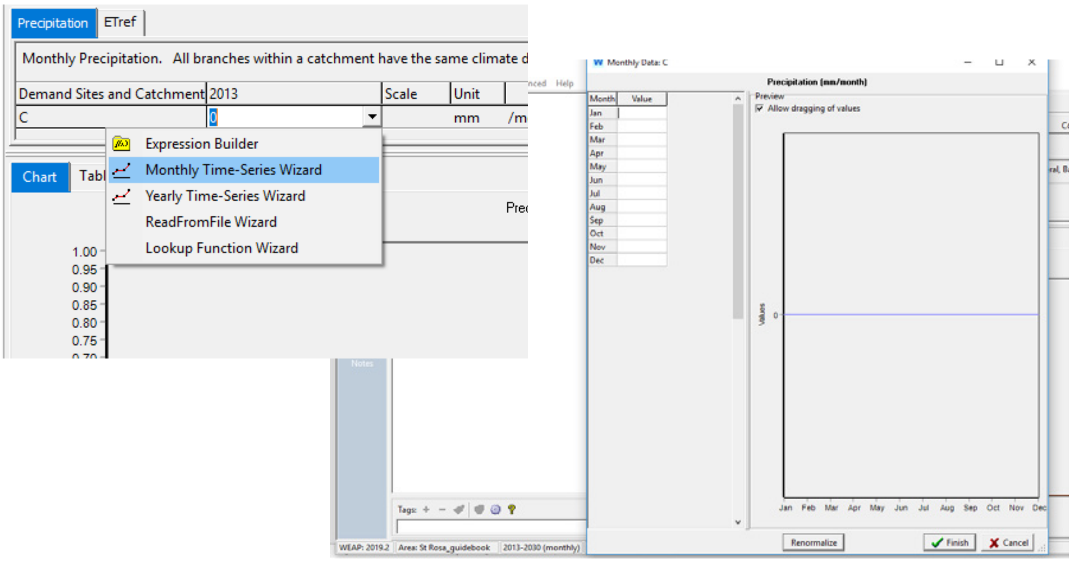
c Now within Land Use Tab, fill all the area information for all the land use types, as shown below.



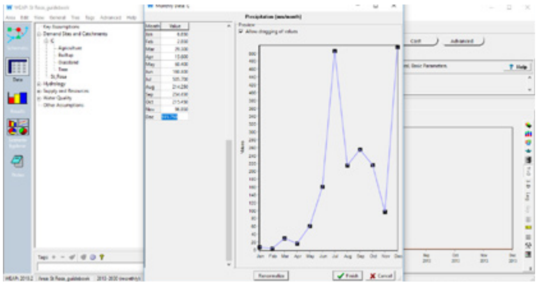


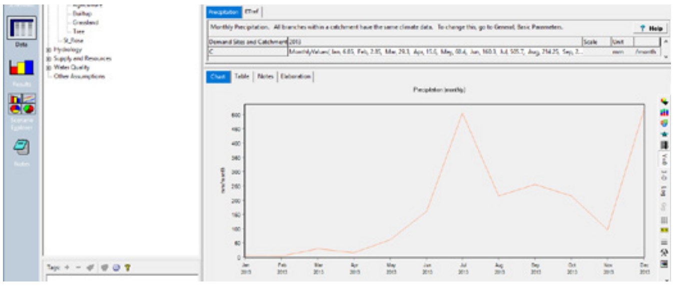


d Now click on the climate tab, and open the precipitation monthly time-series wizard.

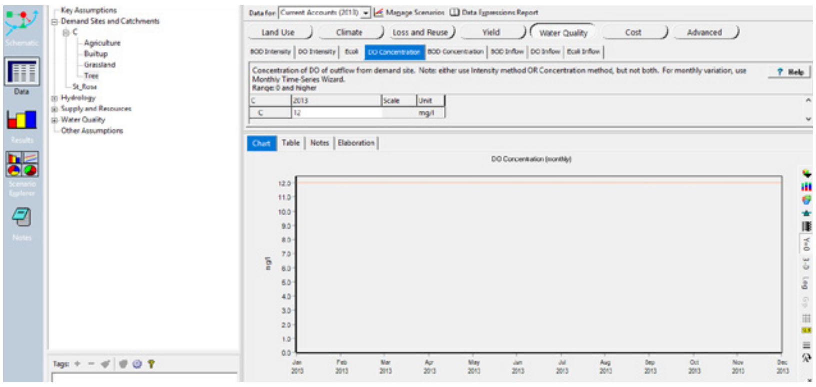


e Enter the monthly precipitation values, shown below

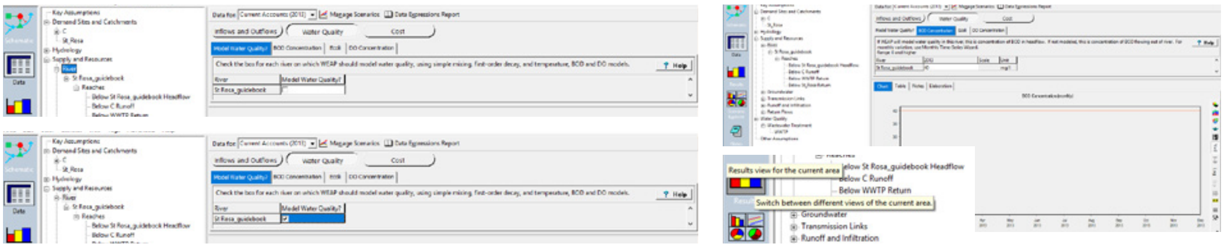




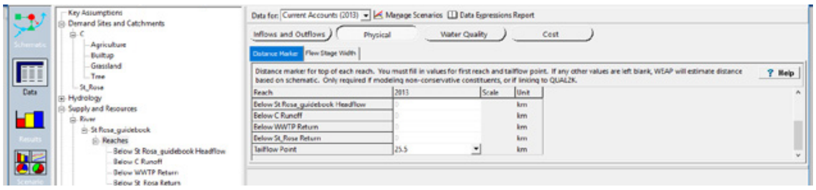
f Next, click the water quality tab. We can give the input in terms of either intensity or concentration of the water quality parameters. We will use concentration, setting a value of 12 mg/l, as shown below.



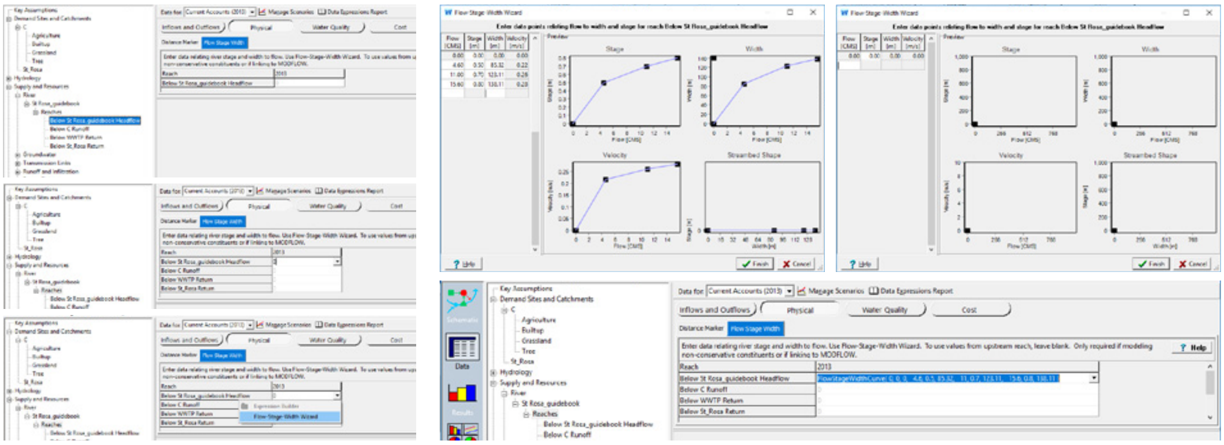
g Now we will give water quality data for the river, but first we have to enable the water quality module within the river as shown below.



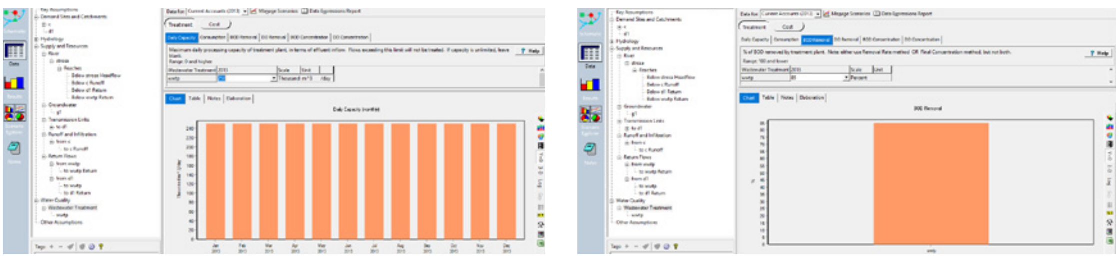
h Now give the value of distance marker and river cross section. For distance marker, as the length of river investigated is 25.5 km, put “0” below river head flow and 25.5 km for the tail flow point.



i For the river cross section, click flow stage width as shown below, and give all the input data shown below.



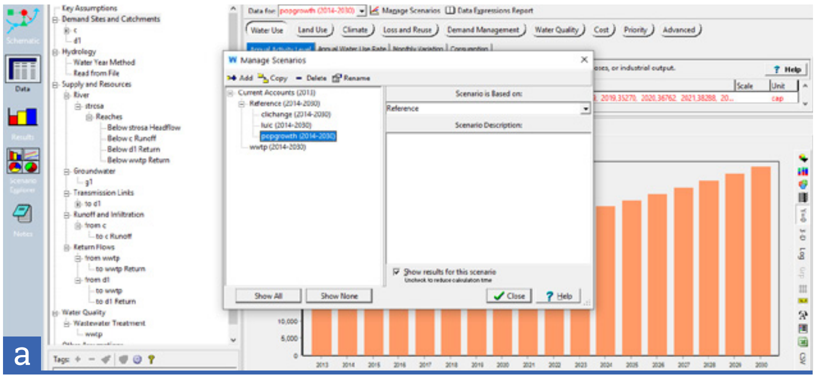
j Now give values for WWTP as a mitigation measures. We gave value for its treatment capacity, removal rate for different contaminants (e.g. BOD as shown below), which we have analyzed in this study as shown in below figure.



Step 11. Generate different scenarios

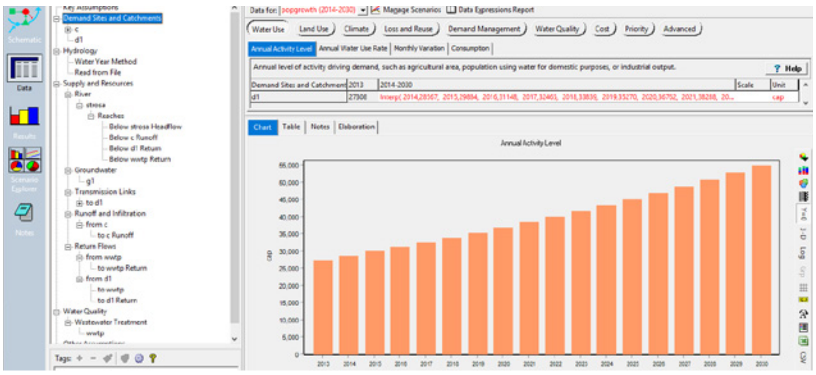
Now once the reference scenario is done, we can start building scenarios to include drivers and pressures which have potential to impact water quality in the future. For our simulation case of Santa Rosa, we have built scenarios including population growth, climate change, mitigation measures i.e. installing wastewater treating infrastructure.

a To build new scenario, click manage scenario, a new window will pop up, where we need to put the name of scenario. Then the message will be asked that this scenario is based on. Select reference as shown in the image below:



Once new scenario is built, then we need to change the concerning parameter in the new scenario, while keeping other parameters same as reference. For example, for a scenario considering population growth, annual activity or population value will be increased from the reference year to the target year as shown in figure below.

b Create a new scenario called popgrowth (2014-2030). Enter the following population values for the years 2014-2030 (in the Annual Activity Level tab):

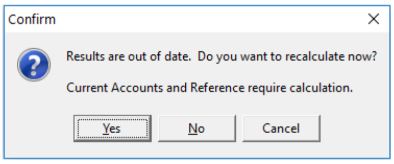


	D1
Year	St Rosa
2013	296619
2014	310293
2015	324598
2016	338328
2017	352639
2018	367556
2019	383104
2020	399309
2021	415880
2022	433139
2023	451115
2024	469836
2025	489334
2026	509005
2027	529467
2028	550752
2029	572892
2030	595922

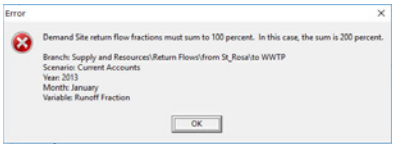
Similarly, when can build scenarios to incorporate the impacts of climate change, land-use change, and new WWTPs. If you'd like to run these different scenarios, please see the "WEAP input data readme.doc" file inside the WEAP_training_St_Rosa folder for the values to input.

Step 12. Run the model (Calibration, validation, simulation)

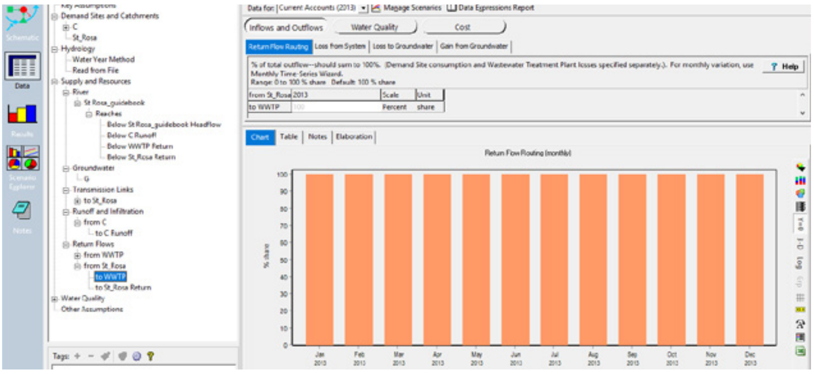
a Once done with data input and saving the model, press result button. There will a pop-out message which will appear is "Results are out of date. Do you want to recalculate now?" as shown below. Press yes.



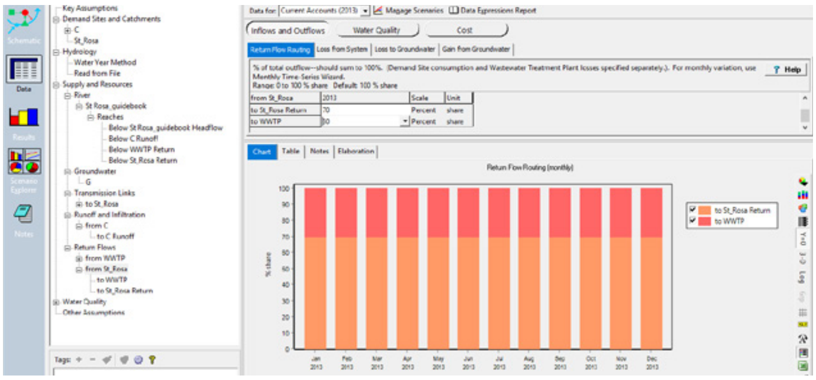
After running the model, we might encounter messages like the following: Demand site return flow fractions must sum to 100 percent. In this the sum is 200 percent. It means I have missed allocating the wastewater going to WWTP for the treatment and remainder coming back to the river as discharge.



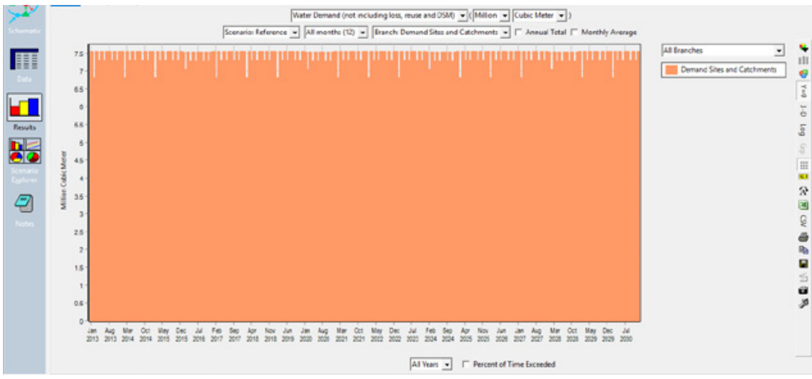
Click Ok and rectify the issue in the window that will pop out thereafter.



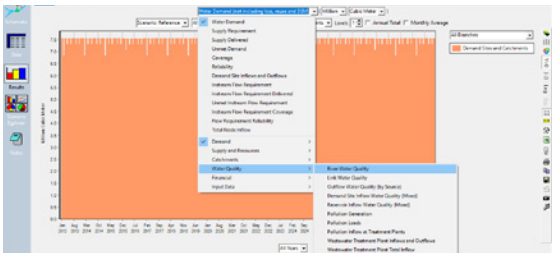
b Click from StRosa from dropdown of return flows on the left side of schematic diagram.

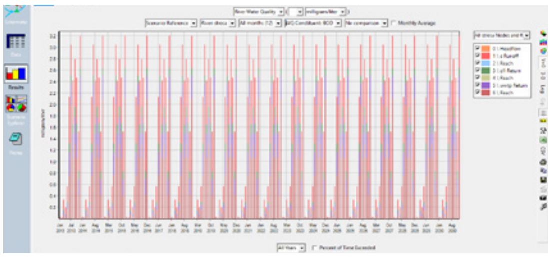


c Now again press result for model simulation, and new window will pop-up showing result for water demand as shown below.

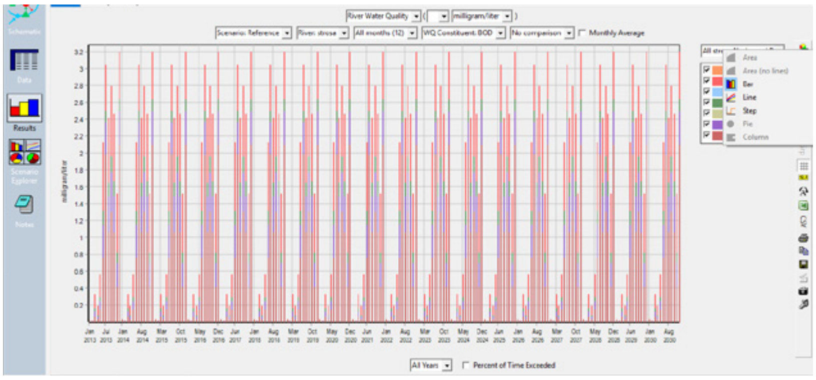


d Now select the desired parameters from the dropdown menu to see the simulated result like water quality as shown below.



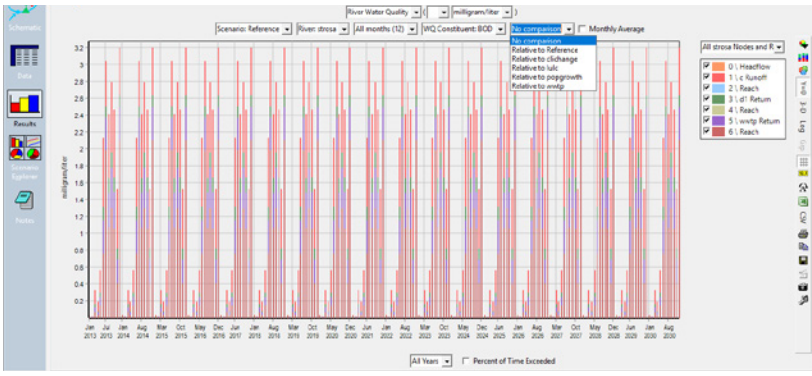


e We can change the chart type like bar, line, stack etc. based on our interest just by clicking and selecting it from side menu.

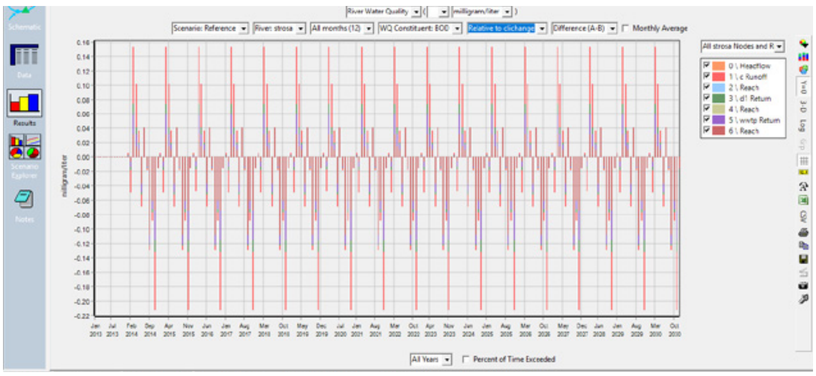


f We can also export this simulated result data as an Excel sheet by right clicking on the windows and exporting these data sets in to the desired folders. Later you can edit these output to draw different graphs as per your convenience.

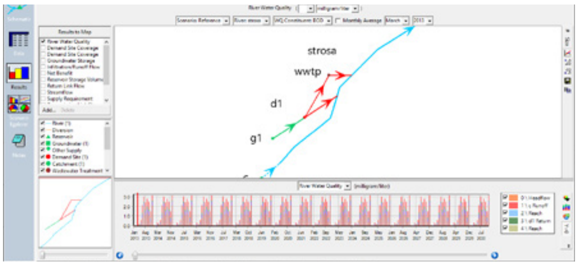
g We can also change the type of graph we wanted to display like no comparison, relative to population growth, land use land cover, climate change, and different mitigation measures as shown in the drop down menu shown below.

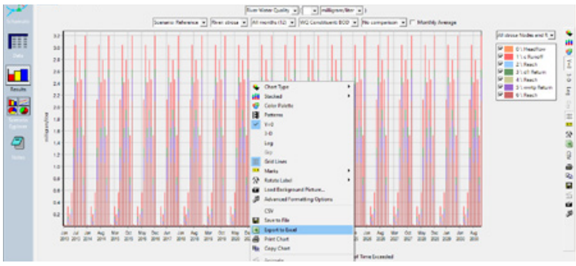


Example: relative to climate change means reference scenario result in compare to climate change scenario



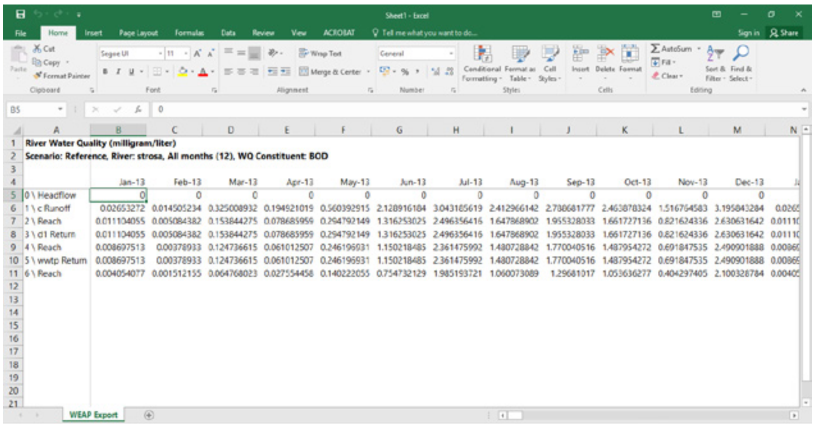
h We can also display the graphs in different ways by selecting the option as shown below. Here result is shown in terms of data along with map.





i The excel file will look this the screen shot shown below.

j Once satisfied with schematic diagram development for problem domain and giving all necessary input data required for simulation, calibration followed by validation need to be done to estimate the credibility of the model performance.



River Water Quality (milligram/liter)

Scenario: Reference, River: strosa, All months (12), WQ Constituent: BOD

	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0 \ Headflow	0	0	0	0	0	0	0	0	0	0	0	0
1 \ c Runoff	0.02653272	0.014505234	0.325008932	0.194921019	0.560392915	2.128916184	3.043185619	2.412966142	2.738681777	2.463878324	1.516764583	3.195843284
2 \ Reach	0.011104055	0.005084382	0.153844275	0.078685959	0.294792149	1.316253025	2.496356416	1.647868902	1.955328033	1.661727136	0.821624336	2.630631642
3 \ d1 Return	0.011104055	0.005084382	0.153844275	0.078685959	0.294792149	1.316253025	2.496356416	1.647868902	1.955328033	1.661727136	0.821624336	2.630631642
4 \ Reach	0.008697513	0.00378933	0.124736615	0.061012507	0.246196931	1.150218485	2.361475992	1.480728842	1.770040516	1.487954272	0.691847535	2.490901888
5 \ wwtp Return	0.008697513	0.00378933	0.124736615	0.061012507	0.246196931	1.150218485	2.361475992	1.480728842	1.770040516	1.487954272	0.691847535	2.490901888
6 \ Reach	0.004054077	0.001512155	0.064768023	0.027554458	0.140222055	0.754732129	1.985193721	1.060073089	1.29681017	1.053636277	0.404297405	2.100328784

k For calibration, following steps were used for two parameters (effective precipitation and runoff/infiltration ratio) and the result is shown in the Table below.

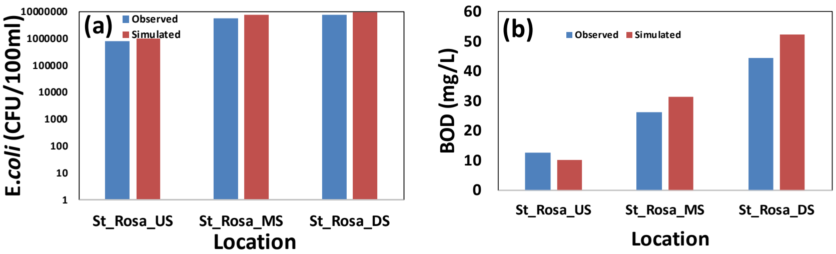
Summary of parameters used and steps for calibration in this study.

Parameters	Initial value	Steps	Final calibrated value for St Rosa
Effective precipitation	100%	± 0.5%	93%
Runoff/infiltration ratio	50%	± 5/5	55/45

l Once statistically satisfied with the model calibration, the next step is validation. For validation, we can compare the observed to simulated values of the water quality parameter(s) from base year to current year.

Here, the result of the validation in our study is shown in figure below. It is found that observed value for both parameters are significantly related.

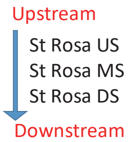
Parameters	Unit	Fishable (Class C)	Bathable (Class B)
BOD	mg/L	4	3
E.Coli. (*Fecal Coliform)	MPN/100ml	5000	500

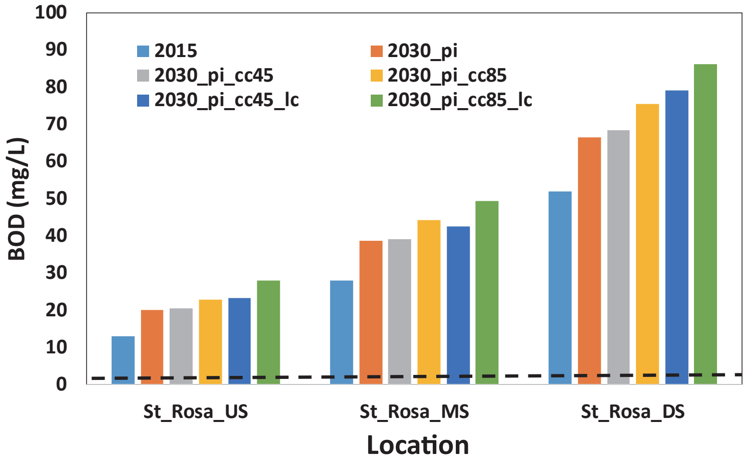


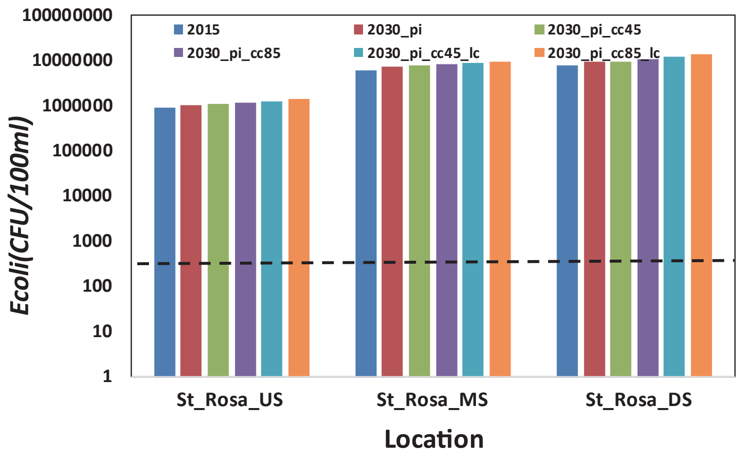
Summary of validation for two water quality parameters i.e. BOD and E.coli

Finally, after validating the model, we can analyze the results of the model simulations. Simulation results for two water quality parameters i.e. BOD and E.coli are shown in the two figures below. These figures were produced by editing the exported data from the model using Microsoft Excel. Please create similar charts using Microsoft Excel or your choice of spreadsheet software. As you have only considered the population growth scenario in this tutorial, your outputs will be a bit different from those shown below.

Simulated Water quality (considering Population growth, Climate change and LULC change)







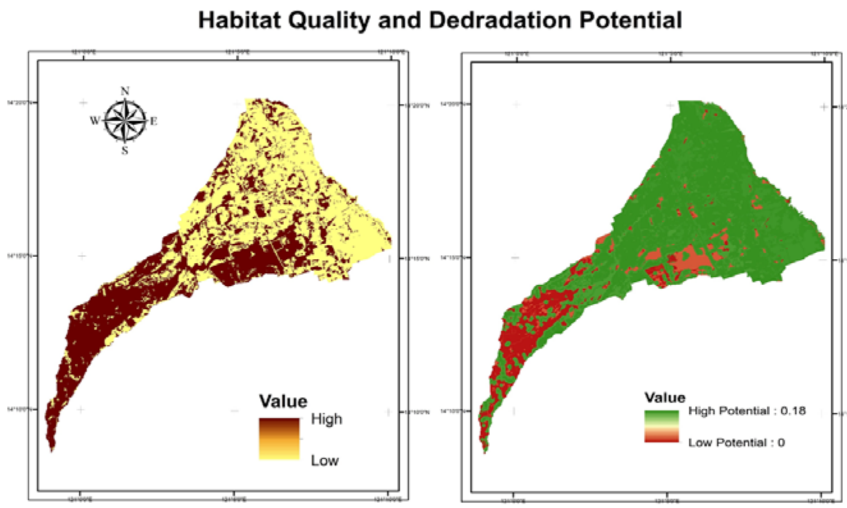
Here, 2015- current condition, 2030_pi – Scenario with population growth only, 2030_pi_cc45 – Scenario with population growth and climate change (moderate RCP 4.5), 2030_pi_cc85 – Scenario with population growth and climate change (extreme RCP 8.5), 2030_pi_cc45_lc – Scenario with population growth, climate change (moderate RCP 4.5) and land use/land cover change, 2030_pi_cc45_lc – Scenario with population growth, climate change (extreme RCP 8.5) and land use/land cover change

Congratulations, you've learned how to perform water quality simulation using WEAP!

References

Sieber, J., Purkey, D. (2011). Water Evaluation and Planning System. User guide for WEAP21; Stockholm Environment Institute, U.S. Center: Somerville, MA, USA; Available online: http://www.weap21.org/.

Chapter 6: Habitat Quality Impact Assessment Using InVEST Software



Overview of this chapter

Land-use changes can affect biodiversity positively (e.g. restoration of a degraded forest), negatively (e.g. conversion of a natural area to built-up land), or in mixed ways. The spatial pattern of the land-use changes is also impactful. For example, if a large forest patch becomes very fragmented, there may not be enough food, water, and other resources in the smaller forest patches for the remaining plants and animals to survive. In other words, these species lose their home, which is scientifically referred to as "habitat". This chapter will show you how to create your own maps of the current and future habitat quality, i.e. the ability of the landscape to sustain biodiversity, using free Geographic Information Systems (GIS) and ecosystem services modeling (InVEST) tools. These maps can help you to conserve the valuable biodiversity within your watershed.

Rajarshi Dasgupta
Brian A. Johnson

After completing the chapter, you will be able to:

- Perform basic data collection and pre-process the data
- Estimate and map habitat quality using the InVEST ecosystem service model

Main concepts

What is Habitat Quality?

Habitat quality refers to the ability of the ecosystem to provide conditions appropriate for a species to survive (based on the amount of resources available for survival, reproduction, and population persistence) (Hall et al 1997). Simply put, high habitat quality supports the propagation of native biodiversity. In this module, we will learn how to conduct habitat quality modeling using the InVEST model. The InVEST model utilizes habitat quality as a proxy for a more detailed biodiversity assessment, which generally requires more time and cost to conduct (e.g. due to the need for intensive field data collection and sampling). In other words, InVEST's habitat quality model provides an indirect assessment of the impacts of land use changes on biodiversity, i.e. how land-use decisions will contribute to the degradation/restoration of biodiversity. Within the InVEST model, habitat quality is determined principally by four factors: the relative impact of each threat to biodiversity, the relative sensitivity of each habitat type to each threat, the distance between habitats and the sources of different threats, and the degree to which the land is legally protected from these threats.

What is InVEST model?

By this time, you must be curious about the InVEST model. InVEST stands for integrated valuation of ecosystem services and tradeoffs. This is a suite of spatially-explicit ecosystem services modeling tools developed by the famous Natural Capital Project of Stanford University. InVEST is a set of 26 biophysical models (many others are under development), which can be run independently, or as script tools in the ArcGIS/ ArcTool Box environment. All of these models are spatially explicit, and thus, use maps as input and generate maps as output. It feeds on spatial information, while the scope of non-spatial information that can be incorporated is more restricted. All of the calculations in InVEST are done at the pixel scale (e.g. a 30 meter x 30 meter grid cell for many commonly used land-use maps). Yet, there are several advantages of using InVEST models. Firstly, they are seldom data intensive, and therefore applicable even in data-deficit regions. The spatial resolution of this model is also very flexible, allowing users to operate at any scale, ranging from local, regional, to even global. This gives it an advantage over conventional ecosystem service modelling tools, which are generally bounded by scales and require a lot of primary data generation. However, as there is no functionality in InVEST for manipulating or viewing the map inputs/ outputs, we need to use other GIS software like QGIS or ArcGIS to prepare the map inputs and view the modelling results. Therefore, to operate InVEST, a basic understanding of GIS software is necessary. Please refer to Chapter 2 for information on how to use QGIS for data preparation and viewing.

Where do you find InVEST download links?

The current version of InVEST is 3.7. This can be downloaded from the following link. However, it is recommended to work on previous version (e.g. 3.6), as the current version may be still under development and may lack some functions.
Model download page: https://naturalcapitalproject.stanford.edu/software/invest
User Manual: http://releases.naturalcapitalproject.org/invest-userguide/latest/

Brief Overview of InVEST Habitat Quality Model

The InVEST Habitat Quality Model is one of the core models under the InVEST Suite, which aim to determine conservation of biodiversity using landscape patterns and fragmentations, using land-use and biodiversity threat maps as proxies. As mentioned, InVEST HQ models habitat quality and rarity as proxies for biodiversity, ultimately estimating the extent of habitat and vegetation types across a landscape, and their state of degradation. Within the InVEST environment, Habitat quality and rarity are a function of four factors: (a) the relative impact of each threat to biodiversity, (b) the relative sensitivity of each habitat type to each threat, (c) the distance between habitats and sources of threats, and the (d) degree to which the land is legally protected from these threats. The model operates on two basic assumptions: that the legal protection of land is always effective (which may or may not be the case, in reality) and that all threats to a landscape are additive.

How it works?

The InVEST Habitat Quality model combines information on land-use/land cover and threats to biodiversity to produce habitat quality maps. This approach generates two key sets of information that are useful in making an initial assessment of conservation needs: the relative extent and degradation of different types of habitat types in a region, and changes across time. This approach further allows rapid assessment of the status of and change in habitat as a proxy for more detailed measures of biodiversity status. If habitat changes are taken as representative of genetic, species, or ecosystem changes, the user is assuming that areas with high quality habitat will better support all levels of biodiversity and that decreases in habitat extent and quality over time means a decline in biodiversity persistence, resilience, breadth and depth in the area of decline.

The habitat rarity portion of the model indicates the extent and pattern of natural land cover types on the current or a potential future landscape vis-a-vis the extent of the same natural land cover types in some baseline period. Rarity maps allow users to create a map of the rarest habitats on the landscape relative to the baseline chosen by the user to represent the mix of habitats on the landscape that is most appropriate for the study area's native biodiversity.

The model requires basic spatial data that are available almost anywhere in the world, making it particularly useful in areas where species distribution data are poor or lacking. Extensive species occurrence (presence/absence) data may be available in many places for current conditions. However, modeling the change in occurrence, persistence, or vulnerability of multiple species under future conditions is often impossible or infeasible. While a habitat approach leaves out the detailed species occurrence data, several of its components represent advances in functionality over many existing biodiversity conservation planning tools; The most significant being the ability to characterize the sensitivity of habitat types to various threats. Not all habitats are affected by all threats in the same way, and the InVEST model accounts for this variability. Further, the model allows users to estimate the relative impacts of each threat, so that threats that are more damaging to biodiversity persistence can be represented as such. For example, grassland could be particularly sensitive to threats generated by urban areas, yet moderately sensitive to threats generated by roads. In addition, the distance over which a threat is likely degrade natural systems can be incorporated into the model. Model assessment of the current landscape can be used as an input to a coarse-filter assessment of current conservation needs and opportunities. Model assessment of potential LULC futures can be used to measure potential changes in habitat extent, quality, and rarity on a landscape and conservation needs and opportunities in the future. For more details regarding the model functions, please see the InVEST use guide manual.

Tutorial

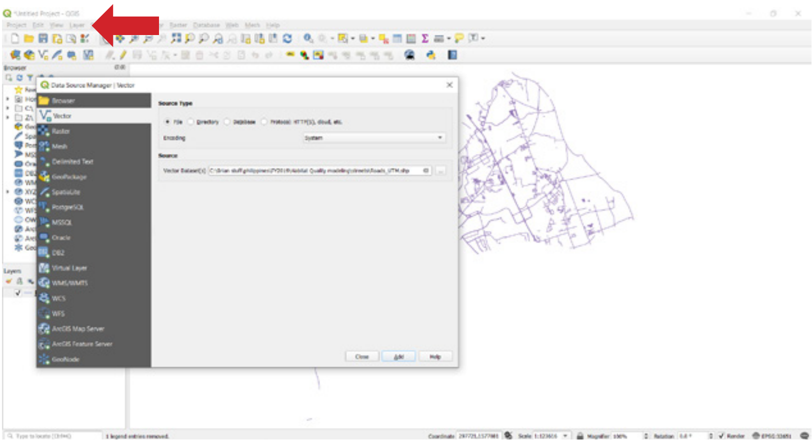
In the following tutorial, you will learn how to run the InVEST model using sample data prepared for the Santa Rosa watershed, Philippines. In practice, habitat quality modelling typically requires data preparation in a GIS environment before inputting it to InVEST. For instance, to run the InVEST model, we need to derive maps of various threats to biodiversity (e.g. based on distance to roads or urban areas), land-use map(s) and the level of perceived threat (in grid, or raster, map format). If you have experience with GIS, preparing spatial data for InVEST is relatively straightforward. Here, we will show how to run the InVEST Habitat Quality model, as well as how to prepare and view the input/output data in QGIS.

a **Open QGIS and start a new project (Click Project -> New).**

Refer back to Chapter 2 if you are unsure how to access or open QGIS.

b Add a map of streets.

First, we will add a streets map of the study area. Click the "Layer" menu and then the "Add vector layer" icon. Navigate to the folder "HQA_DATA\Data for pre-processing" and add the Roads_2014.shp file to the map.

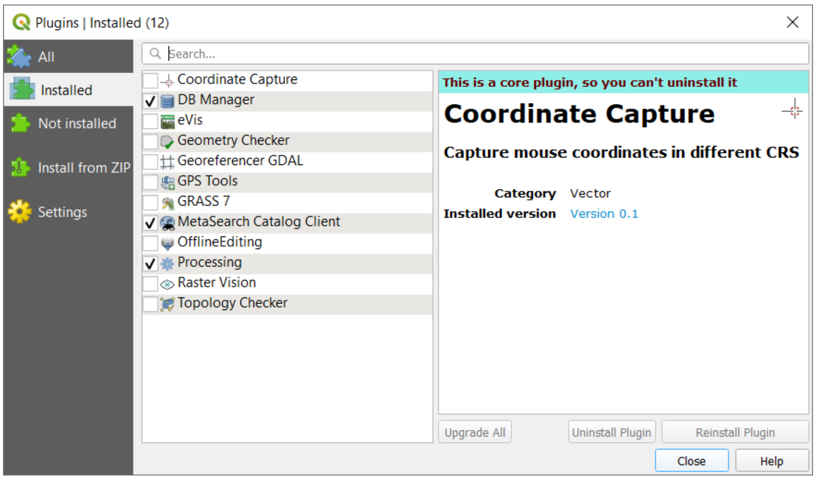


c Add a map of the land-use

Next, we will add the land-use/land-cover maps of the study area, including the year 2015 and 2025 (projected) land-use/land-cover maps. The process is similar to Step 2. Click the "Layer" menu and then the "Add raster layer" icon. Navigate to the "HQA_data/ InVEST HQ Modeling/" folder and add the 2015_LU.tif and 2025_LU.tif files. You can recolor these land-use maps as desired for visualization purposes (refer back to Chapter 3 if you can't remember how to do this).

d Add the "Processing" plug-in for QGIS.

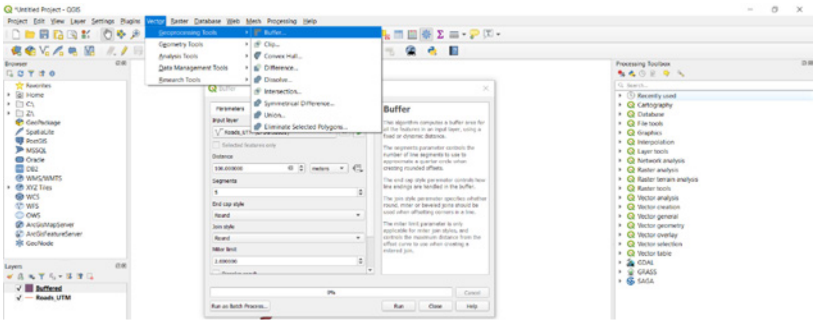
Click on the "Plugins" menu and then click "Manage and install plugins". Click in the box next to the Processing plugin to add plugin to QGIS. Then click "Close".



e Generate a "threat map" by applying a 100 meter buffer to all streets

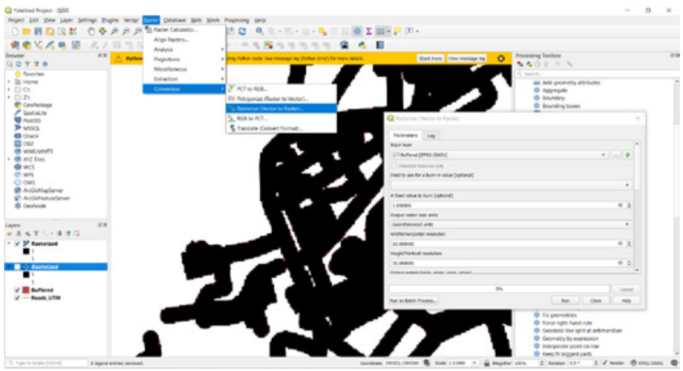
a. Click on the "Vector" menu, highlight "Geoprocessing Tools", and then click "Buffer". Make sure the "Roads_2014" is selected as the input layer, and set the Distance to 100 meters.

b. Save the output to the "Habitat Quality modeling/outputs" folder as a .shp file named "streets_buffered". Finally, click "Run". This should create a new polygon shapefile, with polygons showing all areas within 100 meters of existing roads. For this tutorial, we assume that these areas within 100 meters of roads are likely to experience greater threat to biodiversity (e.g. due to noise, air pollution, and/or physical disturbances of the landscape).



f Convert vector shapefile to raster (.tif) file

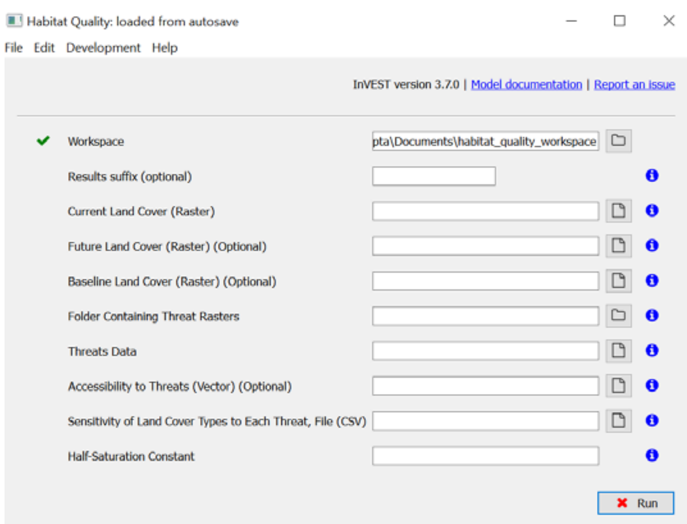
Click on the "Raster" menu, highlight "Conversion", and click "Rasterize (Vector to Raster)". Set the input layer as the buffered shapefile, set the "Fixed value to burn" to 1 (indicating all pixels within the buffer zone will have a value of 1 in the output raster image). Set the "Output raster size units" to Georeferenced units (indicating meters, in this map), and set both the cell width and cell height to 30. For output extent, click … and then "Use layer extent", and select "Roads_2014" as layer the layer extent (click OK). Next, click on "Advanced parameters", and set the Output data type as "byte" (binary values). Finally, under "Rasterized", click the … icon and "Save to file", save the file as streets_buffer.tif.



You have now successfully prepared this threat map for input to InVEST to perform habitat quality modeling. In a real setting, the next step would be to repeat this process for the land-use map, by generating additional buffers around land-use types that pose threats to biodiversity (e.g. built-up areas). The procedure is the same. Inside the Habitat Quality modeling folder, you can find shape files for agriculture and urban areas for 2015. You can repeat the same procedure as mentioned above. All output files should be saved in the threat folder. Here, we will skip this for the sake of brevity, and move on to the procedures for using these input datasets in InVEST.

g Open INVEST Habitat Quality Model

From the Windows "Start" menu, scroll down and click "InVEST 3.6" (or whichever version you have) and then "Habitat Quality". The screen shown below will appear.



h **Set the "Workspace"**

The next step is define the workplace, i.e. the folder containing all of the raster map input files. Please note all of the new files you generate using InVEST will also be saved here. To save time, we have prepared all of the necessary data in the "HQA_data/ InVEST HQ Modeling" folder, so please set it as the workspace.

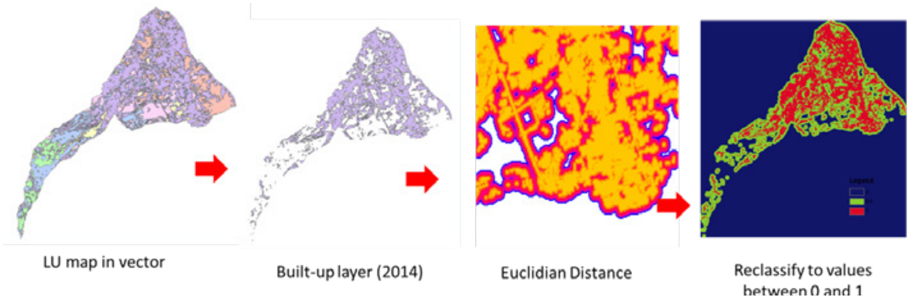
i **From the InVEST HQ Modeling folder, select the Current Land Cover map (2015LU.tif) and Future Land Cover map (2025LU.tif).**

Optionally, if you have a base map (such as an old map), you can use it as reference by setting it as the Baseline Land Cover. Otherwise, please leave it blank. Remember, all of the land-use maps need to be of same spatial resolution and should have the same categories of land use classes.

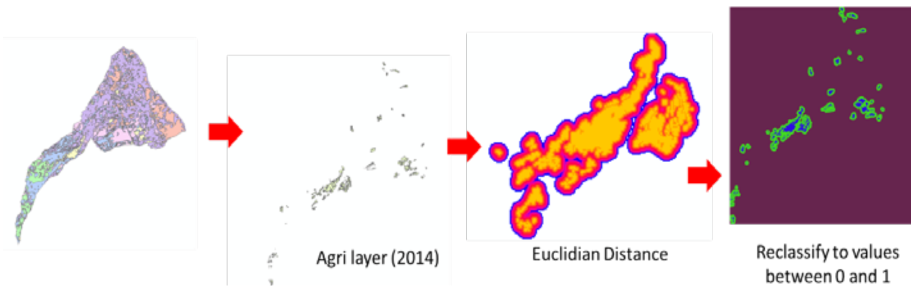
j **Select the folder containing all of the threat maps ("Threat rasters").**

InVEST will automatically find each one in the threat maps in the user-specified Folder, based on names in the Threats data table. Please set this folder as the "HQA_data/ InVEST HQ Modeling/Threat Rasters" folder. As mentioned earlier, threat rasters are maps with values ranging from 0 to 1, with values of 0 meaning that a particular pixel has no influence on habitat quality (i.e. pixels farther than 100 meters from a street, given the threat map generated in Steps 5-6), whereas values of 1 means the pixel has a high threat (i.e. pixels within 100 meters of a street, given the map generated in Steps 5-6). Logically speaking, if we construct a road, the threat value should gradually fade as we go further from it. Here, we have included three threat rasters: one based on the distance to roads (within 100 meters = high threat), another based on distance to built-up or urban areas (within 200 meters = high threat), and another based on distance to agricultural areas (within 200 meters = high threat).

Streets shapefile (left), 100 meter buffer around streets (middle), and final threat raster map (right)



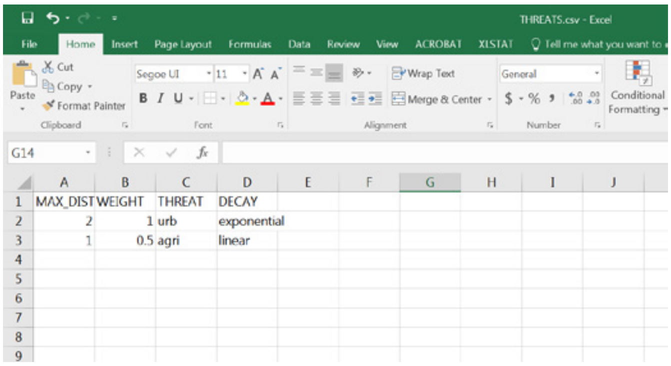
Land-use shapefile with built-up areas extracted (left), 200-meter buffer around built-up areas (middle), and final threat raster map (right)



Land-use shapefile with agricultural areas extracted (left), 200 meter buffer around built-up areas (middle), and final threat raster map (right)

k **Set distance decay functions and weights for each threat**

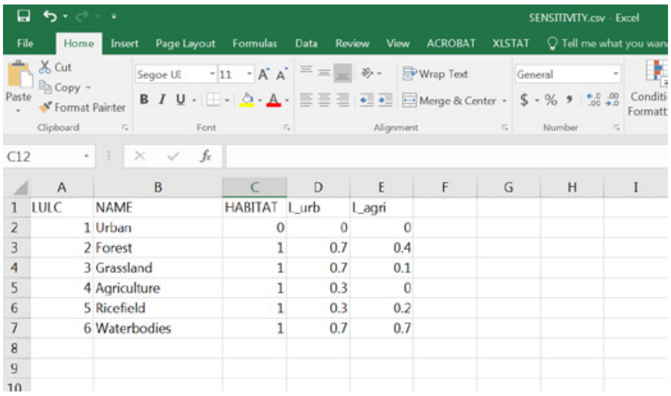
In the threat data column, you need to put a .csv file (threat.csv) with decay functions and weights of threat classes. Please navigate to the HQA_data/ InVEST HQ Modeling folder and select Threats.csv for this parameter. Decay functions can be exponential or linear. You can use a consultative process of experts to determine the maximum distance where the impact of roads, urban area and agriculture area are applicable. For instance, urban areas have more impact (weight) on habitat degradation compared to roads. Thereafter, you can use decay functions either exponential or linear, as deemed suitable. This means that the influence fades out linearly or exponentially.



MAX_DIST	WEIGHT	THREAT	DECAY
2	1	urb	exponential
1	0.5	agri	linear

l **In the sensitivity column, please add the sensitivity.csv file.**

Please note that in practice, these Excel files need to be prepared using literature survey and/or consultative workshops. For instance, you can use Simpson and Sharon diversity indices as proxies to create the sensitivity values for each land use classes. For this, you can use any recent biodiversity survey reports or conduct the survey as your own. In the sensitivity file, we need to identify the habitat class (whether the specific LU class is a habitat or not, identified by 1 and 0), then, provide relative influence (in a scale of 0 to 1, where 1 is highest inference) of each land use class on the others. For example, forest (which is a habitat in this case), is heavily influenced by urbanization and moderately influenced by agriculture. You can put relative scoring based on expert judgment or your own demarcation criteria. The excel file, as shown below, needs to be saved as .csv file. Also, as shown below, please see the naming requirements.

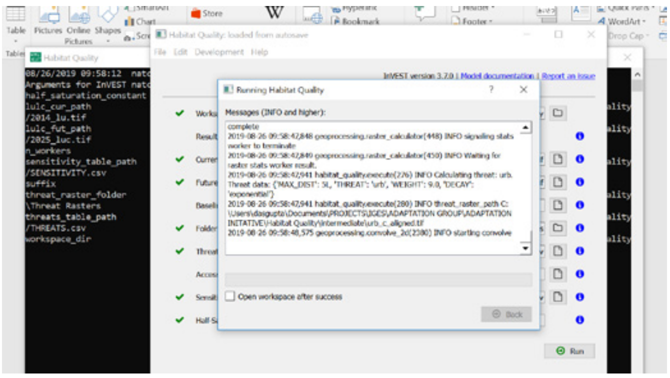


LULC	NAME	HABITAT	L_urb	L_agri
1	Urban	0	0	0
2	Forest	1	0.7	0.4
3	Grassland	1	0.7	0.1
4	Agriculture	1	0.3	0
5	Ricefield	1	0.3	0.2
6	Waterbodies	1	0.7	0.7

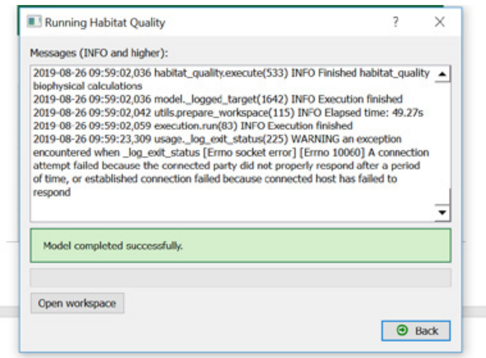
Set the "Half-constant" parameter to 0.5.

m **Click "Run"!**

You will see the following window if all your model parameters are readable by the computer. If not, an error message with suggested changes will appear.



After couple of iterations, your model finally completes. The following window will appear if it is completed successfully.

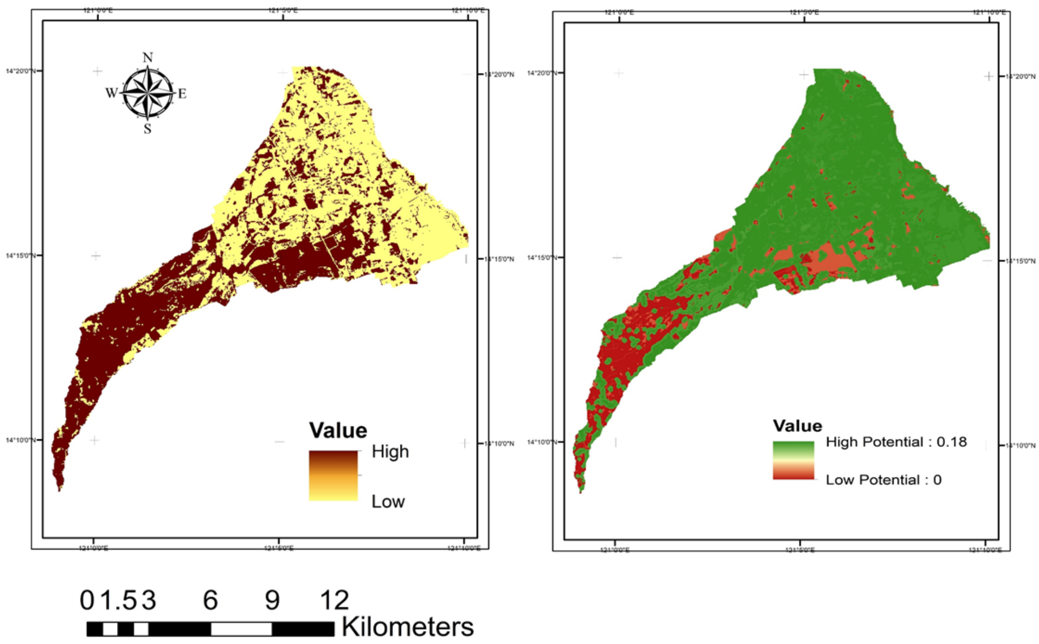


n Open the output maps using QGIS

Navigate to the specified workspace folder. You will see an output folder within your working folder. You will find a series of processed maps inside it. There are two types of maps, which will give you the desired information on (1) current and future habitat quality (quality_c.tif and quality_f.tif) (2) current and future degradation potential (deg_sum_c.tif and deg_sum_f.tif). You can display these file in QGIS by clicking on the "Layer" menu, highlighting "Add Layer" and clicking on "Add Raster layer".

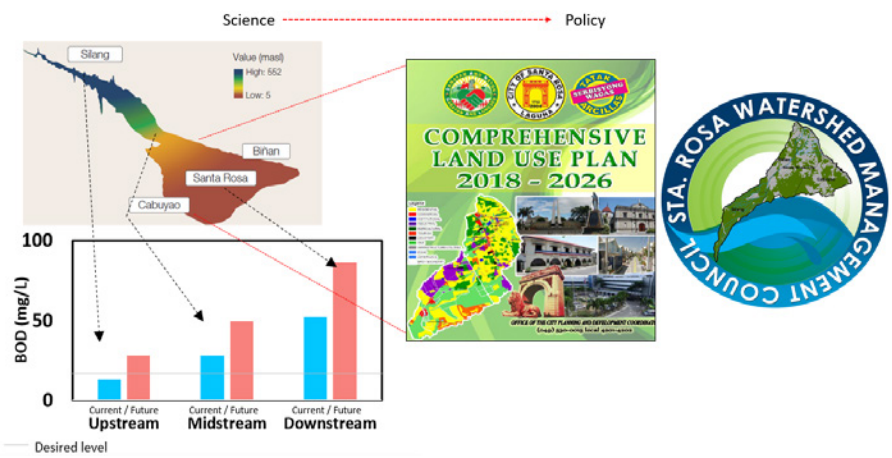
The Habitat Quality map shows the relative level of habitat degradation based on the current and future landscape (i.e. the land-use that exists, the spatial pattern of the land-use, and the threats present). Higher values indicate better habitat quality as well as the distribution of habitat quality across the rest of the landscape. This quality score is unitless and does not refer to any particular biodiversity measure. For degradation potential, a high score in a grid cell means habitat degradation in the cell is high relative to other cells. These cells are susceptible to the loss of biodiversity. You can use different colors and examine the output closely. This is your final modelling product and allows you to compare the habitat quality for both the current and future. Here, we show these final outputs for the current (2015) land-use below.

Habitat Quality and Dedradation Potential



Congratulations, you've learned the basics of habitat quality mapping using InVEST software!

Chapter 7: Identifying and implementing countermeasures to reduce land-use and climate change risks



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Overview of this chapter

As discussed in the previous chapters, land-use changes can exacerbate the impacts of climate change, e.g. by causing increased soil erosion and more rapid rainfall run-off when vegetated areas are converted to impervious/built-up urban areas. The participatory watershed land-use management (PWLM) approach presented in this guidebook provides a framework to assess these impacts, and aids in designing appropriate climate change adaptation measures with local governments and other relevant stakeholders. Previous chapters have focused on the scenario development and impact assessment steps of PWLM. The focus of this chapter is to provide some guidance for adaptation measure development and implementation, utilizing the results of the different impact assessments. It is based mainly on lessons learned from our case study in the Santa Rosa watershed in the Philippines.

In this chapter, you will learn:

- How to identify countermeasures through a participatory process;
- About potential technologies and funding sources for climate change adaptation;
- About mechanisms for enhancing collaboration between local governments for better watershed-level planning, e.g. through the establishment of watershed management councils and payment for ecosystem service (PES) schemes.

Main concepts

Science-based climate actions can be aided by the use a framework that involves several key elements including: identifying potential future climate change scenarios; assessing the impacts of the predicted changes; developing, appraising, and prioritizing management options (e.g., policies, measures); mainstreaming the options into development planning; implementing the options; and monitoring and evaluating the progress and results of the implementation (Endo et al., 2017). The PWLM approach presented in this guidebook incorporates these elements in its four steps. The first two steps of PWLM (Scenario Development, and Impact Assessment) represent the (mostly) technical aspects of this framework, while the third and fourth steps (Countermeasure Development, and Climate Resilient Land-use Planning and Implementation) represent the policy aspects. In this chapter, we demonstrate how these third and fourth steps of the PWLM approach can be implemented through a case study of the Santa Rosa Watershed of the Philippines. This case study is presented here because the local governments made several remarkable achievements, including:

- Identifying land-use change/climate change countermeasures at a watershed scale;
- Incorporating these measures in their land-use plans;
- Developing a watershed management council to better manage land-use and climate change impacts at the watershed scale; and
- Completing training courses on the use of several impact assessment models/software.

Countermeasures to reduce land-use change and climate change impacts are, by their nature, site specific, so the measures presented here should be taken as some good examples rather than "best practices". What is important is that the countermeasures identified contribute to: enhanced collaboration between municipalities, better land-use planning and management at the watershed scale (e.g. to reduce land-use change/climate change impacts on all communities in the watershed), and capacity building to enable government staff to make better decisions related to climate change/land-use change, among other things.

Case Study of Santa Rosa Watershed

Introduction

The Santa Rosa watershed is a watershed at risk of immense degradation; In the past two decades it has undergone massive land-use changes brought about by rapid urbanization and industrialization (Lasco & Espaldon, 2005; Magcale-Macandog et al., 2011), and further land-use changes are expected in the near future. The watershed consists of four local government units: Silang (upstream), and Santa Rosa City, Biñan, and Cabuyao (downstream). These municipalities have experienced a boom in industrial zones, commercial establishments, and high-to-medium end residential developments because of their proximity and good transport links to Metro Manila and Southern Luzon. The watershed plays an important role in the entire region of Calabarzon, one of the most populated regions in the Philippines, because it drains into the Laguna de Bay Lake. The lake is important source of water and livelihood for the communities. It is also important for various economic sectors, serving diverse functions for the fishery sector, providing irrigation water for agricultural sector, serving as transport route for lakeshore dwellers and some other products, generating energy for hydroelectric power and other industrial uses. But the rapid growth in commerce and population is a potential threat to water resources due to loss of recharge areas and wetlands (WWF, 2009), reducing natural capacity of the subwatershed to retain water and hold rainfall during rainy days. It has already resulted in widespread flooding due to excessive runoff from upland areas or from rising lake levels, which were triggered by Typhoon Ondoy in 2009 (Tongson, 2012). Other environmental problems from unsustainable growth in Santa Rosa include water scarcity in urban areas and water pollution in the lake. Ultimately, flooding, water scarcity and pollution affect the households and livelihoods of the communities.

Participatory countermeasure identification

In the Santa Rosa watershed, countermeasures to reduce future land-use change/climate change impacts were identified through consultation meetings with local officials from the City/Municipal Planning Office, City/Municipal Environmental Office and City/Municipal Engineering Office of the local government units (LGUs) located within the watershed. The participants from each LGU were grouped together in one table. The results of the scenario and impact assessments (covered in Chapters 4-6) were presented in the form of maps and charts. The scenarios shown were the current land-use (derived from recent satellite images) and the future land use (for the period ~2025-2030) based on a participatory mapping done in Step 1 of the PWLM approach (Chapter 2).

Using this information, the LGU officials were asked to discuss among themselves to identify the actions that can be taken to address these land-use change/climate change impacts in their locality. The countermeasures could be tailored based on their local physiographic conditions, population distribution, needs, future development plans and availability of resources. They were asked to write their identified countermeasures on notecards, and when completed, all of the notecards were collected and displayed at the front of the meeting room. A representative from each LGU then presented and explained the identified countermeasures to the whole group (Figure 7.1.). In this way, the countermeasures could be shared among all LGUs in the watershed. Finally, there was a question and answer/discussion section to identify and summarize the priority/common countermeasures at the watershed scale.

Figure 7.1. Consultation meeting with LGU officials and identification of countermeasures to reduce the negative impacts of land-use change/climate change.

Priority countermeasures

Having considered the impact of future development and climate change in terms of flooding and water quality, the LGUs devised three categories of priority measures to reduce the negative impact of these changes: Zoning enhancement measures, river rehabilitation measures, and capacity development measures (Table 7.1).

Firstly, improving zoning ordinances aimed to ease and/or evade flood risks by, for example, regulating development and relocating informal settlers in highly flood-prone areas. Runoff mitigation measures (including tree planting, green roofs/green parking lots) were also suggested to be mandated when forest or agricultural land is converted for other purposes, so-as to reduce flood impacts and mitigate water quality degradation (e.g. due to increased erosion or runoff of pollutants).

Table 7.1. Priority measures to reduce the negative impacts of land-use change/climate change on flooding and water quality.

Measure	Description	Action	Land-use / land-cover
Zoning enhancement	To avoid and alleviate climate impact, and to sequester carbon dioxide	Enforce development controls and strengthen building codes (e.g. elevated flooring) in areas highly susceptible to flooding Construction of floodwalls. Devise relocation plan for informal settlers in flood-prone areas.	When forest or agricultural land is converted to built-up areas, mandate runoff mitigation measures such as tree planting, green parking design, water-permeable paving, and vegetated roofs. Take actions for the strict enforcement of zoning ordinances. Harmonize land-use among the local governments to make the river basin more resilient to climate-related disasters.
River rehabilitation	To increase water retaining capacity and reduce erosion (e.g., reforestation, river cleanup, dredging, and riverbank reinforcement)	All areas	Regular river cleanup
		Upstream area	Protection and improvement of environment through replanting of endemic and indigenous plant species
		Midstream area	Proper zoning and land use planning Rehabilitation of easement and riverbanks Slope protection along riverbanks
		Downstream area	Control encroachment of settlements in easement areas Dredging of sediments Solid and liquid waste management Planting of endemic and indigenous plant species Improvement of drainage
Capacity development	To build and strengthen the ability of local government to design and implement climate actions	Needs assessments (NA) on CCA, CCM , disaster preparedness and management	Develop survey/assessment instrument to determine the needs for training and public awareness activities; Conduct the NA.
		Development of campaign materials and training modules for CCA, CCM , disaster preparedness and management	Develop campaign materials and training modules for CCA, CCM, disaster preparedness and management.
		Conduct of trainings and events	Organize trainings and events to increase awareness and preparedness.

In regards to river rehabilitation, a number of ecosystem-based and structural countermeasures were identified as priority countermeasures. Foremost of these countermeasures was river rehabilitation through dredging, river clean-up, and slope protection of river banks. The Santa Rosa river is the major drainage system in the watershed. Figure 7.2 shows that it contains many narrow streams and tributaries (<10 meters width) in the upstream areas that feed into the main river that culminates at a dam (Macabling dam). Beyond the dam are narrow (Figure 7.2) and shallow (Figure 7.3) irrigation canals and drainage canal systems that supply irrigation water to rice fields in the downstream area since the Spanish colonial era. These canal systems are not designed for urban drainage, and easily overflow during heavy rains/typhoons, resulting in frequent flooding in the city. Solid wastes dumped in the riverine channels tend to clog the narrow drainage channels, which further exacerbates the risk of flooding. Thus, regular river and drainage clean-up was decided as necessary to allow the free flow of rain water and run-off water to minimize occurrence of flooding in the city. River dredging was another countermeasure to increase the river depth in the downstream area and thus increase the carrying capacity of the riverine system. The riverbanks in the upstream and midstream areas of the river system are prone to riverbank erosion, particularly during the typhoon season (Figure 7.4). Thus slope protection of river banks through reforestation of upstream areas and riparian areas will minimize the risk of river bank erosion.

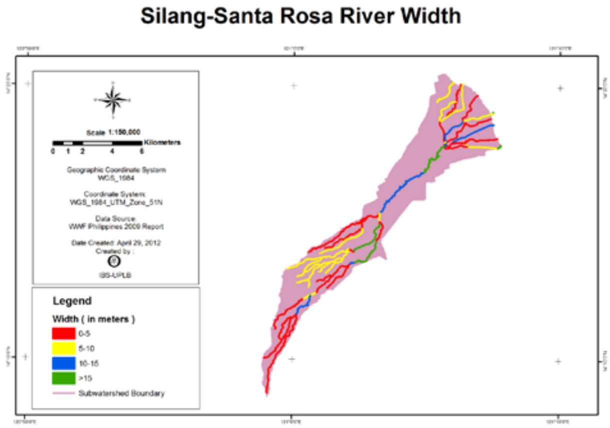


Figure 7.2. Santa Rosa river width. (Source: Zafaralla et al., 2012)

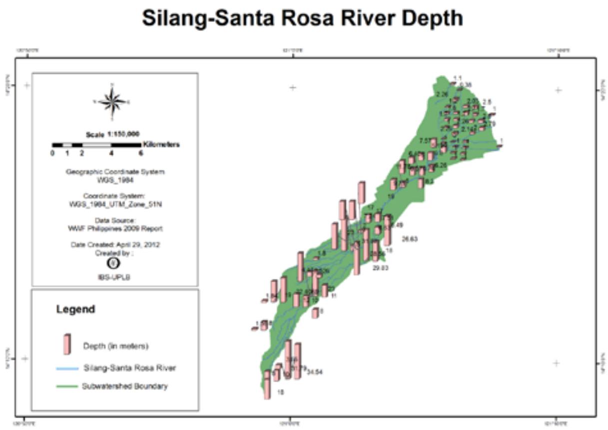


Figure 7.3. Silang-Sta. Rosa river depth. (Source: Zafaralla et al., 2012)

Figure 7.4. (a) Depth of flooding and debris, and (b) eroded river banks of Sta. Rosa-Silang River. (Source: Zafaralla et al., 2012)

Lastly, the LGUs proposed that training activities should be implemented to strengthen the capacity of local government staff. This includes the assessment of training needs and the development of training materials. Along these lines, a series of training workshops were organized in 2019-2020 (photos shown in Figure 7.5.) to build the capacities of the LGU staff to conduct their own land-use change and climate change impact assessments using the free models/software presented in Chapters 3-65 of this guidebook (QGIS, WEAP, InVEST). Participants who completed these trainings were given certificates, and technical support was provided to help the LGU staff utilize these tools for their planning processes.

Figure 7.5. Training workshop for LGU staff on impact assessment models/software (right) and water quality analysis methods/tools (right).

Proposed projects for implementing the identified measures

As part of the identification of countemeasures, immediate actions were also proposed according to the needs of each local government (Table 7.2). To avoid and alleviate flood risks, it was suggested that the building codes in high-risk areas in the downstream area (Santa Rosa City) be strengthened and that Land Developer's guidelines be prepared in the upstream municipality (Silang) to implement runoff mitigation measures where forest and/or agricultural land is converted. Watercourse management projects in the downstream basin were also recommended to maintain and improve watershed protection function (i.e., flood alleviation, water retention ability) of ecosystem. Additionally, the activities for operationalizing an integrated watershed management council (IWMC), called the Santa Rosa Watershed Management Council, were proposed.

Table 7.2: List of proposed projects.

Project	Objective	Activity	Expected output	Proponent
Operationalize Integrated Watershed Management Council (IWMC)	Operationalize IWMC	Council meetings Rules of procedure Action plan Joint activities Monitoring / supervision	Rules of procedure/ institutional arrangement established Initial activities designed/ initiated	Laguna Lake Development Authority
Watercourse management	Enhance watershed protection function	Riverbank reinforcement Dredging River cleaning Afforestation & reforestation	Water retention ability of river system maintained/ improved	Biñan, Cabuyao, Santa Rosa LGUs
Local building codes	Strengthen building codes in high-risk areas to protect people and assets	Draft local ordinances to mandate runoff mitigation measures Administer legislative actions to request for approval Monitor/ supervise compliance	Local building codes devised and implemented	Santa Rosa LGU
Land developers guidelines	Promote sustainable land development and conversion	Draft administrative guidelines for the private sector to implement runoff mitigation measures Organize IEC to familiarize stakeholders of proposed guidelines Monitor/ supervise compliance	Developers guidelines devised and implemented	Silang, in cooperation with Santa Rosa LGU

Identifying funding opportunities for proposed projects

The next step after identifying these actions/projects is to look for potential funding agencies to support and finance these projects. Two possible external funding sources were identified for this financing: one national fund called the People Survival Fund (PSF), and one international fund called the Green Climate Fund (GCF). The PSF is special fund in the Philippine National Treasury that finances climate change adaptation programs and projects. GCF, on the other hand, is a dedicated fund set up by the United Nations Framework on Climate Change (UNFCCC) in 2010 to help developing countries reduce their GHG emissions and enhance their ability to respond to climate change.

A series of planning workshops with the LGU officials of the Sta. Rosa-Silang subwatershed was conducted to brainstorm and plan for the development of a proposal for PSF. The outline of the People's Survival Fund (PSF) proposal was designed in one of the planning workshops. The projects that were included in the PSF proposal were the identified action projects presented in Table 7.2. A Technical Working Group was established to discuss the PSF proposal. Parallel to these planning workshops with LGUs is the conduct of consultation meetings with the Laguna Lake Development Authority (LLDA) and the Climate Change Commission. The objectives of the meetings with LLDA were to present and discuss the framework of the proposal for PSF as well as to seek support and involvement of LLDA in the project implementation. One of the major concerns in the packaging of the proposal is the submission of the proposal by multiple LGUs and LLDA. At one point, the idea of LLDA as the lead implementing agency of the project was explored. The development of the PSF proposal underwent several drafts and improvement by the researchers (IGES-UPLB team), LGUs and LLDA. Consultation meetings were also done with the Climate Change Commission to gather more information about the funding scheme, requirements for the proposal submission and to explore the possibility of submitting a proposal by multiple cities. A draft of the PSF proposal was shared with CCC for initial comments.

Development of GCF project proposal based on this project is under consideration and still early stage. CCC is the National Designated Authority to endorse all proposals for GCF. CCC looks at the quality of the proposal before endorsing to GCF. Land Bank is the national accredited entity implementing GCF projects. One SAP (Simplified Approval Process) project, "Multi-Hazard Impact-Based Forecasting and Early Warning System for the Philippines" has been approved by GCF secretariat in November 2019 in Philippines. The project will strengthen the Philippines' ability to adjust to climate impacts, and implement long-term climate risk reduction and adaptation measures. It will build on best practice in multi-hazard early warning systems and link with forecast-based action to maximize impacts on the ground. This includes climate-resilient development planning and investment (GCF website: https://www.greenclimate.fund/project/sap010). Further information on GCF proposal development and the process can be obtained from GCF official website (https://www.greenclimate.fund/)

Aside from external funds for projects, green bonds are another important future opportunity of fund raising from private sector and local government. Green Bonds are defined as "Bonds issued in order to raise finance for climate change solutions and labelled as green by the issuer. They can be issued by governments, banks, municipalities or corporations and can be applied to any debt format" (Climate Bond Initiative 2018). Green Bonds have been rapidly spreading in the world. The amount of global Green Bond issuance was USD3.1 billion in 2012; however, in 2018, issuance grew to USD167.3 billion (Ministry of the Environment based on data on the CBI website). The Securities and Exchange Commission (SEC), Philippines has approved on 16 August 2018, the "Guidelines on the Issuance of Green Bonds under the ASEAN Green Bonds Standards." These Guidelines set out to adopt the ASEAN Green Bond Standards and provide for the rules and procedures for the issuance of ASEAN Green Bonds in the Philippines. The eligible Green Project categories includes but are not limited to 1) Renewable energy, 2) Energy efficiency, 3) Pollution prevention and control 4) Environmentally sustainable management of living natural resources and land use , 5) Terrestrial and aquatic biodiversity conservation, 6) Clean transportation 7) Sustainable water and wastewater management, 8) Climate change adaptation, 9) Eco-efficient and/or circular economy adapted products, 10) production technologies and processes and 11) Green buildings. These categories all can involve/cover the adaptation options identified in this Chapter. Further information on the trend of Green Bond can be obtained from following websites:

International Capital Market Association:
https://www.icmagroup.org/green-social-and-sustainability-bonds/green-bond-principles-gbp/

Climate Bonds Initiative: https://www.climatebonds.net/

The Green Bond Issuance Promotion Platform: http://greenbondplatform.env.go.jp/en/

Potential adaptation technologies

Since this project was supported by the Ministry of the Environment of Japan, it is possible to introduce adaptation technology developed in Japan, another country facing climate related disasters in recent years. The Japanese government publishes technologies owned by private companies on the Climate Change Adaptation Platform (A-PLAT: https://adaptation-platform.nies.go.jp/en/lets/adaptationbiz.html).

In addition, Santa Rosa city previously developed "Land Developers Guidebook for the Santa Rosa Watershed" in 2011 with support from WWF. It introduces several best storm water management practices (1. Reducing impervious surfaces, 2. Low impact development, 3. Water detention ponds, 4. Grass filter strips, 5. Grassed swales, level spreader, 7. Rock-line channel, 8. Check dams, 9. Sediment basin, and 10. Sediment trap). Effective use of the results and outputs of such past projects is also important.

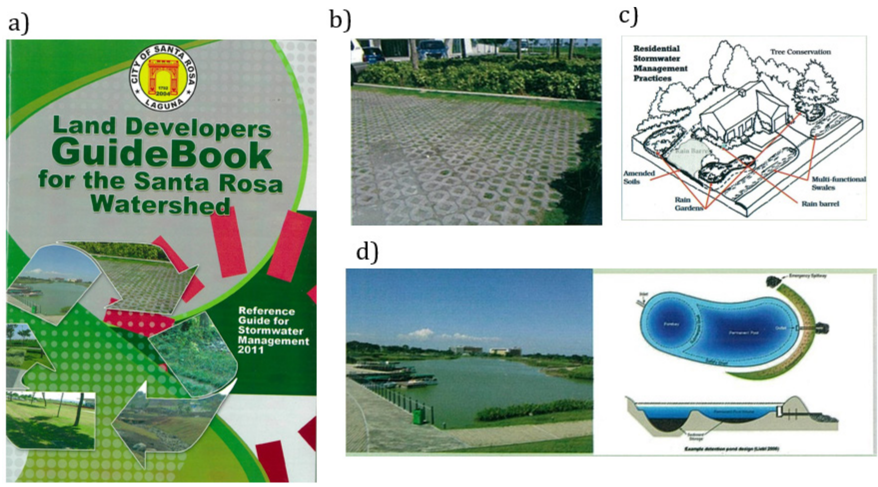


Figure 7.5. Training workshop for LGU staff on impact assessment models/software (right) and water quality analysis methods/tools (right).

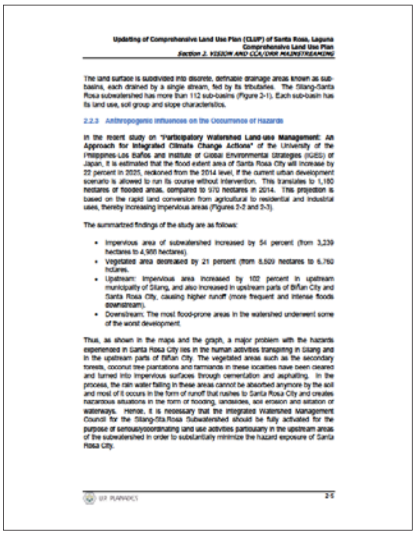
Enhancing collaboration between local governments for watershed-level planning

An Integrated Watershed Management Council for the Santa Rosa watershed was formalized by the signing of a Memorandum of Agreement (MOA) among the mayors of the four LGUs in the watershed and the General Manager of the Laguna Lake Development Authority (LLDA) (Figure 7.7). This became the very first watershed management council established in the entire Laguna Lake basin, and aims to harmonize land-use and make collective efforts to address weather-related disasters at the watershed level. The council members include the LLDA (national government agency to provide oversight/coordination) and the four LGUs, as well as water utility companies, river councils, NGOs, and private companies (including Asia Brewery and Malayan University). Since 2017, with the election of the IWMC officers led by LLDA, the council is conducting quarterly meetings to create and implement the integrated watershed management plan. The continuing success of the IWMC lies in the continued commitment and active participation of its members.

Figure 7.5. Training workshop for LGU staff on impact assessment models/software (right) and water quality analysis methods/tools (right).

Incorporating countermeasures into land-use plans

The local governments in the Santa Rosa watershed are in the process of revising their Comprehensive Land-use Plans (CLUPs), following not only the Republic Act No. 9729 stipulating that climate change shall be mainstreamed into government policy formulations (Congress of the Philippines, 2009), but also the national guidelines requiring that local climate change actions shall be mainstreamed into CLUPs (Housing and Land Use Regulatory Board, 2013). Upon the approval by the Housing and Land Use Regulatory Board and the Sangguniang Panlalawigan (i.e. provincial assembly), the CLUPs serve as the basis for formulating the local Comprehensive Development Plan (CDP) and Local Development Investment Programs (LDIP) (Housing and Land Use Regulatory Board, 2013). It is essential that the scientific information provided through these types of impact assessments be incorporated into these local plans. Notably, the City of Santa Rosa revised their CLUP based on the climate change countermeasures and flood hazard maps produced using the PWLM approach (Figure 7.8.) (City of Santa Rosa, 2016).



Updating of Comprehensive Land Use Plan (CLUP) of Santa Rosa, Laguna
Comprehensive Land Use Plan
Section 2. VISION AND CCA/DRR MAINSTREAMING

The land surface is subdivided into discrete, definable drainage areas known as sub-basins, each drained by a single stream, fed by its tributaries. The Silang-Santa Rosa subwatershed has more than 112 sub-basins (Figure 2-1). Each sub-basin has its land use, soil group and slope characteristics.

2.2.3 Anthropogenic Influences on the Occurrence of Hazards

In the recent study on "**Participatory Watershed Land-use Management: An Approach for Integrated Climate Change Actions**" of the University of the Philippines-Los Baños and Institute of Global Environmental Strategies (IGES) of Japan, it is estimated that the flood extent area of Santa Rosa City will increase by 22 percent in 2025, reckoned from the 2014 level, if the current urban development scenario is allowed to run its course without intervention. This translates to 1,180 hectares of flooded areas, compared to 970 hectares in 2014. This projection is based on the rapid land conversion from agricultural to residential and industrial uses, thereby increasing impervious areas (Figures 2-2 and 2-3).

The summarized findings of the study are as follows:

- Impervious area of subwatershed increased by 54 percent (from 3,239 hectares to 4,988 hectares).
- Vegetated area decreased by 21 percent (from 8,500 hectares to 6,760 hctares.
- Upstream: Impervious area increased by 102 percent in upstream municipality of Silang, and also increased in upstream parts of Biñan City and Santa Rosa City, causing higher runoff (more frequent and intense floods downstream).
- Downstream: The most flood-prone areas in the watershed underwent some of the worst development.

Thus, as shown in the maps and the graph, a major problem with the hazards experienced in Santa Rosa City lies in the human activities transpiring in Silang and in the upstream parts of Biñan City. The vegetated areas such as the secondary forests, coconut tree plantations and farmlands in these localities have been cleared and turned into impervious surfaces through cementation and asphalting. In the process, the rain water falling in these areas cannot be absorbed anymore by the soil and most of it occurs in the form of runoff that rushes to Santa Rosa City and creates hazardous situations in the form of flooding, landslides, soil erosion and siltation of waterways. Hence, it is necessary that the Integrated Watershed Management Council for the Silang-Sta.Rosa Subwatershed should be fully activated for the purpose of seriouslycoordinating land use activities particularly in the upstream areas of the subwatershed in order to substantially minimize the hazard exposure of Santa Rosa City.

UP PLANADES 2-5

Fig. 7.8. Revised CLUP of Sta Rosa City (2018-2026) and the incorporation of the PWLM outputs for countermeasures to climate change.

Potential for payment for ecosystem services (PES) schemes at the watershed scale

Finally, payment for ecosystem services (PES) schemes were mentioned to be of interest by the LGUs in the Santa Rosa watershed. The downstream LGU (Santa Rosa City) was particularly interested in providing payments to the upstream LGU (Silang) to conserve the natural habitats around the river so-as to mitigate flooding and maintain/improve the river water quality. However, they expressed that PES is difficult to implement for many technical and non-technical (political and legal) reasons, as well as due to lack of experience among the LGUs in regards to PES. To support these PES efforts, a series of concept notes on "Economic analysis in the Santa Rosa watershed: Scoping the possibility for a payments for ecosystem services (PES) scheme" was written with the following parts:

1. Understanding the Theoretical Framework of a Payments for Ecosystem Services (PES) Scheme
2. Considerations in designing PES schemes: Targeting Ecosystem Service Buyers and Sellers
3. Considerations in designing PES schemes: Establishing Ecological Linkages and Valuing Ecosystem Services
4. Considerations in designing PES schemes: Land Management Options for PES Schemes
5. Considerations in designing PES schemes: Determining the Price of Ecosystem Services and Funding for PES
6. Considerations in designing PES schemes: Establishing Payment Mechanisms
7. Overview of PES Cases in the Philippines

Please see Appendices for these write-ups.

Conclusion

In this final chapter of the PWLM Guidebook, we have presented a case study to demonstrate how countermeasures, identified through the PWLM approach, can be identified and then implemented to increase the resilience of coastal communities in climate hazard-prone regions. We sincerely hope that this guidebook, including the various tutorials included in it, can help you to identify the future impacts of climate change and land use change in your own locality, and to develop policies and projects to reduce these future risks.

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