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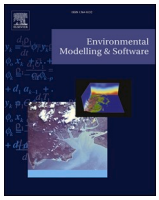

LUCST: A novel toolkit for Land Use Land Cover change assessment in SWAT+ to support flood management decisions

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ABSTRACT

Land Use Land Cover (LULC) change is widely recognised as one of the most important factors impacting the hydrological response of river basins. SWAT+, the latest version of the Soil and Water Assessment Tool, has been used extensively to assess the hydrological impacts of LULC change. However, the process of making and assessing such changes in SWAT+ is often cumbersome and non-intuitive, thereby reducing its usability amongst a wider pool of applied users. We address this issue by developing a user-friendly toolkit, Land Use Change SWAT + Toolkit (LUCST), that will: (1) allow the end-user to define various LULC change scenarios in their study catchment, (2) run the SWAT+ model with the specified LULC changes, and (3) enable interactive visualisation of the different SWAT+ output variables. A good System Usability Score (79.8) and positive feedback from end-users promises the potential for adopting LUCST in future LULC change studies.
Video abstract: https://youtu.be/QygBidYr4cQ.

1. Introduction

Land Use Land Cover (LULC) change is recognised as one of the most important factors impacting overland runoff, the hydrological response of river basins, and fluvial flooding (DeFries and Eshleman 2004; Sajikumar and Remya, 2015). Consequently, many studies have linked flooding directly to LULC change, e.g., Apollonio et al. (2016), Zope et al. (2016) and Posthumus et al. (2008), in the Cervaro basin (Italy), the Oshiwara basin (India) and Ure basin (England) respectively. Anthropogenic LULC changes have the capacity to propagate the adverse impacts of climate change on the hydrological response of catchments (Marhaento et al., 2018; Van Roosmalen et al., 2009). However, properly implemented catchment management has the potential to be a useful impact mitigation measure against climate change (Burby and French, 1981; Branca et al., 2013; Parker, 2014). It is therefore imperative that catchments are managed carefully to help mitigate and not exacerbate the impacts of climate change. The first step towards good catchment management, as recognised by the United Nations Sendai Framework for Disaster Risk Reduction 2015–2039, is to understand the disaster risk at hand (UNISDR, 2018).

The first principles of hydrological modelling were introduced by Mulvaney (1851) and were used in the rational formula of Kuichling (1889) in what could be one of the very earliest hydrological models (Montanari, 2011). Later, Sherman (1932) proposed the unit hydrograph model, a method of hydrological assessment commonly used to this day. However, since the attempt by Crawford and Linsley (1966), hydrological modelling has predominantly become an ever more complex digital activity. By the end of the 20th century, advances in computing power and increased understanding of hydrological processes led to complex process-based hydrological models. These process-based hydrological models are an (idealised) mathematical representation of a given catchment that calculate numerous physical outputs (e.g., flow, sediment, water quality). LULC change impact assessments can be made using these models by altering the land use input and comparing the outputs to that of other scenarios. TOPography based hydrological MODEL (TOPMODEL) (Beven et al., 1995, 2021; Scanlon et al., 2000; Gao et al., 2017), the European Hydrology System (MIKE SHE) (Refshaard and Storm, 1995; Graham and Butts, 2005; Rujner et al., 2018) and the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998, 2012) are just a few examples of the most popular process-based models.

SWAT is a deterministic, semi-distributed, process-based

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hydrological model. It is described as a multi-scale, time-continuous catchment model (Arnold et al., 1998) and over the last 30 years, it has become one of the most widely used hydrological models in the world (Wu et al., 2020; Bieger et al., 2017). Originally developed to quantify the impact of land management practices in small to large multi-complexity catchments (FAO, 2021), SWAT is considered one of the most suitable models for predicting the impact of LULC on catchment processes (Arnold and Fohrer, 2005; Gassman et al., 2007; Ullrich and Volk, 2009). Consequently, SWAT is a useful catchment management tool (Gassman et al., 2007; Ahn and Kim, 2019). The model is used by several governmental organisations, particularly in the United States, such as the US Department of Agriculture's Conservation Effects Assessment Project (CEAP) (Wu et al., 2020; Scavia et al., 2017; White et al., 2014) and the US Environmental Protection Agency (Yen et al., 2016). Fu et al. (2019) added the names of 42 catchment models or modelling platforms to the search terms on Scopus and found that between 2003 and 2018, SWAT accounted for 44% of papers published, proving the model's popularity.

Despite SWAT's many merits, there has been a growing understanding of its shortcomings in recent years, with many experts highlighting pollutant routeing and a lack of flexibility (in reference to catchment configuration) as major limitations (Arnold and Fohrer, 2005; Gassman et al., 2007; Krysanova and Arnold, 2008). SWAT+, a revised version of SWAT, was developed to address such issues, improve code maintenance and foster the development and integration of new tools into the model by external researchers (Bieger et al., 2017). Released in 2018, SWAT+ already has a strong pool of users and is gaining popularity over previous versions of SWAT. Whilst maintaining the same core algorithms and same input data, SWAT+ was designed to streamline and simplify the modelling process whilst offering the user more flexibility regarding the spatial representation of interactions and processes (Bieger et al., 2017).

When assessing the impact of LULC change in SWAT+, a method often referred to as the 'fixing changing' method (Yan et al., 2013; Woldesenbet et al., 2017; Awotwi et al., 2019; Shukla and Gedam, 2019) is employed. Also referred to as the 'one-factor-at-a-time' analysis (Zhang et al., 2020) or 'delta approach' (Shukla and Gedam, 2019), this method involves changing a single input or factor (in this case, land use) whilst all other inputs remain fixed, thereby isolating the cause of the impact(s) to a single factor (i.e., land use). There are two main ways of implementing the 'fixing changing' method when studying the impact of land use change using the SWAT+ model. The first, and seemingly the most widely used, is to produce a new LULC map for each scenario, which essentially re-delineates the HRUs within the catchment (Lee et al., 2008; Subedi et al., 2013; Cecílio et al., 2019; Tavangar et al., 2021). The second is to alter the SWAT+ input files, adding new land uses and plant communities to the model as well as changing the HRUs land use values in 'hru-data.hru', but maintaining the original spatial set-up of the HRUs (Fig. 1) (Mwangi, 2016; Ahiablame et al., 2019). Each method comes with its own inherent challenges, and both can be time-consuming and non-intuitive.

In previous versions of SWAT, mid-simulation land use changes could be made via SWAT's LUC module. SWAT Landuse Update Tool (SWAT-LUT), an interface developed by Moriasi et al. (2019), interacts with the LUC module to facilitate mid-simulation land use changes. In SWAT+, Decision Tables (DTLs) can be used by expert users in a similar way (Arnold et al., 2018). However, as far as we are aware, at the time of writing, there are no plug-ins or programs that specifically aid in the construction of LULC change scenarios and the analysis of their impact in SWAT+.

Visual analytics have transformed how we process and understand data in several domains. As indicated by Keim et al. (2008), visual analytics aim to make the processing of data more transparent for analytic discourse through visual representations of the said data. Visual Analytics have been used in various domains such as urban planning (Karduni et al., 2017), coastal monitoring (George et al., 2014), and earth system climate change sensitivity analysis (Steed et al., 2013), to name a few. With success in environmental and scientific information analysis (Thomas and Cook, 2006), the potential benefits of visual analytics in hydrological modelling can be utilised to advance of catchment management. SWATOnline has already successfully utilised visual analytics to enhance understanding of the response of catchments to climate change (McDonald et al., 2019).

This paper introduces the Land Use Change SWAT+ Toolkit (LUCST), a web-based and open-source visual analytics application to streamline LULC change assessment in SWAT+ modelled catchments. The array of fluxes (including flow, sediment, NH_3, NO_3, temperature etc.) simulated by SWAT+ means that the model can be used to assess not only flooding impacts but also hydrological balance, water quality, and a range of other catchment processes. Here, we have discussed the utility of LUCST primarily as a flood risk management support tool, specifically with an example of a small catchment in Wales. However, its research use cases are not merely confined to this application and have the potential to aid in wider catchment management.

2. Methods

2.1. LUCST programming

LUCST is a web-based application written in HTML, CSS and JavaScript. A list of the JavaScript libraries used in the application can be found in Table 1.

Currently, to use LUCST, the application files are downloaded from GitHub, and a locally hosted server makes them accessible through a web browser. A Python server handles the "front-end" functions, whereas an express server handles the "back-end" functions. Node.js is used as an Application Programming Interface (API) between the web browser and SWAT+. By using Node.js, the constraints of the browser can be bypassed to allow LUCST to interact with SWAT+ files.

LUCST makes LULC changes by interacting with a number of SWAT+ input and output files from the 'TxtInOut' directory (Table 2). The files that LUCST interacts with can be categorised into two types: 'passive' and 'interactive'. Passive files are read, but their contents are never altered, whereas the interactive files are both read and their contents modified.

To interpret and edit the 'TxtInOut' files using JavaScript, they are

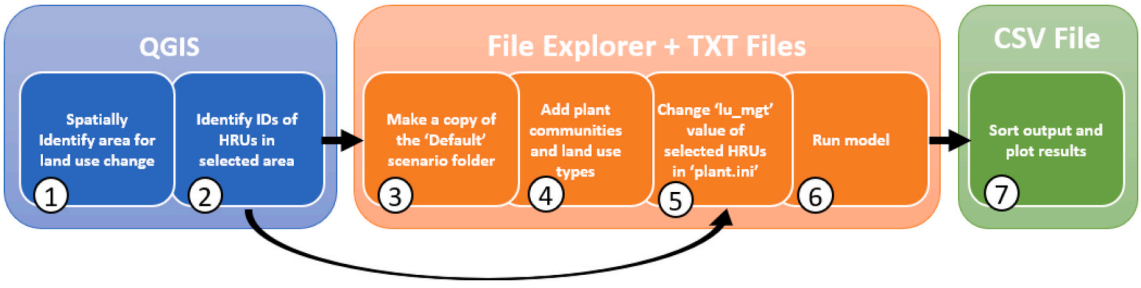

Fig. 1. Simplified breakdown of steps to make land use changes manually in the SWAT+ model.

Table 1
All JavaScript libraries and plugins used to develop LUCST.

Libraries and Plugins		Uses	Toolkit Feature
Leaflet.js		Map generation	Spatial selection map
Plugins	leaflet-lasso.js	Layer selection plugin	Lasso selection tool
	shp.js	Map window generation (background maps from Mapbox)	Adding layers to map, Choropleth plot
	leaflet.shapefile.js	Converts geoJSON to layers	Adding layers to map
	catline.js	Worker plugin to support shp.js	Adding layers to map
D3.js		Parse TSV and CSV files as JSON format	Land use change table, New plant community and land use forms
Vega-lite.js		Plotting data	Generating time series and choropleth plots

uploaded to the server and converted to a JavaScript Object Notation (JSON) file. LUCST uses functions from the JavaScript library D3.js to parse and convert both CSV and TSV formatted files to JSON format. Text files outputted by SWAT+ are not always in a consistent format. In these cases, JavaScript's 'regex' (regular expression) is used to format the text files to TSV before parsing with D3.js.

For 'passive' files, the converted data is read from the JSON files and displayed in various ways in the browser. For 'interactive' files, those where edits are made and saved by a specific action (e.g., clicking 'SAVE ALL' in the Land Use Change Table), the newly edited JSON file is sent to the server where it is converted back to TSV or CSV format. Then, using the Node.js API, the file is written to disk in the current scenarios 'TxtInOut' directory under its correct name (e.g., 'landuse.lum', 'plant.ini') and replaces the previous version.

2.2. User interface

2.2.1. Scenario management

The SWAT+ 'Scenario' directory created during catchment set-up contains all the user defined scenarios, i.e., all variations of a modelled catchment. 'Default' is the first scenario created to represent the actual catchment conditions for the modelled period. The 'Default' scenario must remain unchanged to provide a baseline for meaningful comparison. LUCST ensures the preservation of the 'Default' scenario in 2 ways. The first is through control settings on the interface that disable any 'active' toolkit features when 'Default' is selected. The second is through coded-in safety checks that ensure the 'Default' scenario is not selected when any 'interactive' interface feature is activated (e.g., selecting a land use and clicking 'SAVE ALL' in the Land Use Change Table).

By clicking the 'Create New Scenario' button, a new scenario is written to the 'Scenarios' directory, which, other than its unique name, is an exact copy of the 'Default' scenario. Each scenario in the 'Scenarios' directory is added to the Scenario Tab on the LUCST interface. When a scenario is selected, the directory's name is passed to all JavaScript functions as the directory path for LUCST to both read from and write to. Both passive and interactive functions are enabled when the selected scenario is any other than the 'Default', thereby allowing LULC changes to be made.

2.2.2. Spatial selection map and Land use change table

Leaflet.js, an open-source JavaScript library for map rendering, is used to generate the map and its various components. The channels, HRUs, and sub-basins shapefiles from the SWAT+ catchments 'Watershed' file are converted to geoJSON format using the Leaflet.js plugins ('leaflet.shpfile.js' and 'shp.js'). The geoJSON objects are added as layers to the Leaflet.js map. The original shapefile attributes, except for 'Landuse', are encoded as 'properties' of the geoJSON objects and map

Table 2
SWAT+ 'TxtInOut' files used both passively and interactively by LUCST.

File Name	Passive/ Interactive	Toolkit Feature	Description of Function in LUCST
hru-data.hru	Interactive	Land use change table	Read: HRU 'id' and 'lu_mgt'. Write: new 'lu_mgt' to corresponding HRU.
landuse.lum	Interactive	Land use change table, New land use form	Read: land use 'name' and key parameter values used as drop-down options and tooltips in the land use change table. Write: new user defined land use.
plant.ini	Interactive	New land use form, New plant community form	Read: 'pcom_name' value used in land use form 'plant community' input field drop-down options and 'name' input in new plant community form. Write: new user defined plant community.
channel_sd_day.csv	Passive	Time series plot	Read: data used to generate time series plot.
hru_wb_mon.csv	Passive	Choropleth plot	Read: data used to generate choropleth plot.
plant.plt	Passive	New plant community form	Read: 'name' and 'description' values used as drop-down options and tooltips for new plant community form 'Plant Name' input field.
urban.urb	Passive	New land use form	Read: 'name' and 'description' values used as drop-down options and tooltips in new land use form 'Urban' input field.
filterstrip.str	Passive	New land use form	Read: 'name' and 'description' used as drop-down options and tooltips in new land use form 'Filter Strip' input field.
septic.str	Passive	New land use form	Read: 'name' values used as drop-down options for new land use form 'Septic Tanks' input field.
tiledrain.str	Passive	New land use form	Read: 'name' values used in new land use form 'Tile Drainage' input as drop down options
cntable.lum	Passive	New land use form	Read: 'name' and 'description' values used as drop-down options and tooltips for new land use form 'Curve Number' input field.
ovn_table.lum	Passive	New land use form	Read: 'name' and 'description' values used as drop-down options and tooltips for new land use form 'Manning's n' input field.
cons_practice.lum	Passive	New land use form	Read: 'name' and 'description' values used as drop-down options and tooltips for new land use form 'Conservation Practice' input filed.
grassedww.str	Passive	New land use form	Read: 'name' and 'description' values used as drop-down options and tooltips for new land use form 'Grassed Waterways' input field.
chandeg.con	Passive	Hydrograph	Read: 'out_tot' value used to determine main channel, automatically plots time series plot for the main channel when the page loads

layers. The individual 'lu_mgt' (land use) values from the scenarios 'hru-data.hru' file are assigned to the toolkits HRU layers as 'land use' property's.

The Leaflet.js plugin 'leaflet-lasso.js' is used by LUCST for HRU selection. Leaflet-lasso.js allows a spatial selection to be made by clicking and dragging the mouse over the desired map area. Layers with the 'HRUS' property (i.e., only HRU layers) that fall into the lassoed area are assigned to an array (list of selected HRUs). Each HRU has the property, 'HRUS', which corresponds to the 'id' value from 'hru-data.hru'. Therefore, the map layer's 'HRUS' values are used to identify the selected HRUs and their land uses by their 'id' value in the 'hru-data.hru' file.

The land use change table is generated and populated with the array of selected HRU 'id' values and their 'lu_mgt' values. A drop-down list of all the 'name' values from SWAT+'s 'landuse.lum' allows a new land use to be selected. The land use of individual HRUs or all selected HRUs can be changed at once. When the change is saved (by clicking 'save' or 'SAVE ALL'), LUCST loops over each data point in 'hru-data.hru' and changes the 'lu_mgt' of the selected HRUs to the new user-selected land use. The new 'hru-data.hru' file automatically replaces the old one to update the selected scenario.

2.2.3. New Land use and plant community forms

The LUCST interface with an input form allows new land uses to be written to the 'landuse.lum' file. Each input field in the form corresponds to a 'landuse.lum' parameter. For SWAT+ to run correctly, no parameter can be left valueless, so the new land use will not be saved unless all input fields are populated with a value. Table 3 gives a list of all 'New Land Use Type' input fields and descriptions.

Each parameter in 'landuse.lum' is defined in a connecting file. The available values from connecting files are presented as drop-down lists in the corresponding input fields. SWAT+ land uses can include either a plant community or an urban (and urban runoff) value, so when one is selected in the form, the other is automatically set to 'null' (an accepted SWAT+ parameter value). Some parameters whose connecting files are not usually generated automatically by SWAT+ are automatically set to null (although they can be defined manually by an expert user). The new land use is automatically assigned a name based on the selected plant community or urban land use (with the suffix '_lum').

Adding a new plant community is generally the first step to generate a new land use. Similar to 'landuse.lum', an input form in LUCST is used to create a new plant community, which must be written in the 'plant.ini' file. All SWAT+ pre-defined plant types are available to choose from in a drop-down list. All other input fields are automatically set to the 'typical' SWAT+ plant community values but can be altered if a more specific plant community is required. If the 'Landcover Status' ('lc_status') is set to 'n' (meaning the plant hasn't grown at the start of the model) the 'Initial Leaf Area Index' ('lai_ini') is automatically set to '0'. Similarly, if the 'Landcover Status' is 'y' (yes), the 'Initial Leaf Area Index' cannot be set to 0. The plant community name value is automatically set as the value for 'plt_name' with the added '_comm' suffix (as per SWAT+ standards). Table 4 gives a list and description of the 'New Plant Community' form input fields. Similar to land use, no input field can be left valueless.

At its current stage of development, the toolkit does not provide the capability to add multiple plant types to a community. In consideration of this limitation, the input field for 'plt_cnt' (plant count) was not added to the interface. Instead, the 'plt_cnt' value is automatically set as '1' (as there can only be one plant type in the new plant community).

2.2.4. Model run and result visualisation

LUCST runs SWAT+ rev60.5.2_64rel.exe (executable), which we have made available to download on GitHub with the toolkit. When the 'Run SWAT+' button is clicked, the EXE file is activated and runs SWAT+ for the selected scenario. Once the model run is complete, the outputs are automatically uploaded for visualisation. Both the plots that can be seen in the user interface are generated using 'Vega-lite.js', an open-source JavaScript library for data manipulation and visualisation.

Data for the time series plot is read from the SWAT+ output 'channel_sd_day.csv' (channel data at a daily timestep). In the current version of LUCST, channel data can only be visualised at a daily timestep. The output headers from 'channel_sd_day.csv' are available to choose from a drop-down list in the 'Plot Time Series Box' as well as a list of the catchment channels. A JSON object is created from the values of the selected output of the selected channel per day along with their corresponding dates. The JSON object is updated when the output or channel options are changed. The data from this JSON object is plotted on a time series plot as well as the corresponding data from the 'Default' scenario for output comparison. Digital images of both plots can be downloaded. Alternatively, the raw data from the current time series plot can be downloaded (automatically titled) as a CSV file.

GeoJSON data is required by Vega-lite.js to render geographical areas. The 'shp.js' plugin is used to convert the HRUs shapefile (from the SWAT+ 'Watershed' directory) into a geoJSON object. This geoJSON object is the choropleth plot's primary data source, thereby enabling

Table 3
New Land Use Type form input fields and descriptions.

Input Name	Field Name in landuse.lum	Connected file	Description
Name	Name	n/a	Automatically populated in the toolkit with either plant type or urban. Must have '_lum' suffix
Calibration Group	cal_group		Specify land use belongs to specific calibration group
Plant Community	plnt_com	plant.ini	Plant community present in land use if urban value is 'null'
Management	Mgt	management.sch	Management operations, leave value as 'null' if not needed
Curve Number	c2	cntable.lum	Runoff curve number, parameter to predict direct runoff or infiltration from rainfall
Conservation Practice	cns_prac	cons-prac.lum	Code for conservation practices, uses USLE (universal soil loss equation)
Urban	Urban	urban.urb	Urban land use. If plant community is selected then urban must be 'null'
Urban Runoff	urban_ro	n/a	Urban runoff simulation code determines how urban runoff is calculated and is used to estimate sediment and nutrient loadings
Manning's n	ov_mann	ovn_table.lum	Overland manning's n value gives estimate of flow over hillslope
Tile	tile	tiledrain.str	Presence of tile drains (drainage of subsurface water usually from agricultural land)
Septic Tanks	sep	septic.str	Presence/type of onsite wastewater system
Filter Strip File	vfs	filterstrip.str	Presence/type of filter strip, strip of dense vegetation on hillslope to intercept runoff from upslope pollutant
Grassed Waterways	grww	grassedww.str	Presence/type of grassed waterways or vegetation within channels
Best Management Practices	bmp	bmpuser.str	No built in SWAT+ options. Allows removal of constituents from model based on user defined management practice

Table 4
New Plant Community form input field names and descriptions.

Input Name	Field Name in 'plant.ini'	Description
Plant Name	plt_name	Drop down list of all the pre-defined plant types in SWAT+ (connects to 'plant.plt' file)
Plant Community Name	pcom_name	Automatically populated with plt_name + '_comm' suffix
Rotation Beginning Year	rot_yr_ini	Year of simulation during which plants first come into rotation
Landcover Status	lc_status	Does the plant provide land cover at the beginning of the simulation
Initial Leaf Area Index	lai_init	Leaf area per unit of ground/trunk area of a plant
Initial Dry Biomass	bm_init	Initial dry biomass in kg/ha
Heat Units to Maturity	phu_init	Number of growing degree days needed to bring plant to maturity
Plant Population	plant_pop	Plant Population
Years to Maturity	yrs_init	Number of years from start of simulation until plant is mature
Initial Residue Cover	rsd_init	Initial residue cover/stover in kg/ha

HRU rendering. Spatial data plotted on the choropleth is read from the SWAT+ output file 'hru_wb_mon.csv' (HRU water balance data at a monthly timestep). In the 'Plot Choropleth' box, all 'hru_wb_mon' headers are available to choose from a drop-down list as well as each month that the simulation has been run. The values of chosen output for the chosen month are added to a JSON object along with the corresponding HRU numbers. The HRU numbers from the JSON object are matched to the HRU numbers on the choropleth plot and the data are plotted.

2.2.5. Tooltips

Some elements on the LUCST interface need further description to be clearly understood, especially for less technical users. Tooltips were used to provide these descriptions without taking up window space. Descriptions of these elements were either taken from the SWAT+ input documentation or the 'description' column found in some of the SWAT+ input files.

2.3. System usability scale (SUS) and usability survey

The System Usability Scale (SUS) is a method developed for low-cost and reliable assessments of the usability of systems and applications (Brooke, 1996). The usability of a system must be viewed and measured in terms of how appropriate it is for the task for which it is used. However, usability is a subjective concept, and the components which fall under its umbrella, in the context of system evaluation, are hard to define quantitatively. These components are: effectiveness (the ability of users to complete tasks using the system, and the quality of the output of those tasks), efficiency (the level of resource consumed in performing tasks) and satisfaction (users' subjective reactions to using the system). SUS is an instrument designed to respond to these issues and assess the usability of a system with a simple but carefully designed set of 10 standard questions answered using an agree-disagree Likert Scale. For this study, similar to the method used by Bangor et al. (2009), the original word 'system' was substituted for 'application' in every question to make the questions more answerable for the participants.

Individual sessions were conducted with 12 possible LUCST end-users: a mix of hydrologists, environmental scientists, postgraduates, and various relevant graduate degree holders. During the sessions, the participants were asked to use LUCST to make a new plant community and land use type, to implement a land use change in a catchment and then run the model, analyse the plots, and download the results. When the experience was still fresh in their mind the participants were asked to fill out the SUS questionnaire, the results of which were compiled once all sessions were complete.

For a more holistic evaluation of the application commensurate with the SUS methodology, participants were asked to answer two open-ended questions which gave them an opportunity to provide textual feedback on specific likes/dislikes. A specific feature analysis section was also included where the participants rated each feature overall on a scale of 0–4. Finally, the participants were asked to rate their familiarity with the SWAT+ model (1 being 'Not Familiar' and 5 being 'Very Familiar') to investigate how this affected their answers in other areas of the study.

3. Results

The LUCST Graphical User Interface (GUI) (Fig. 2) is designed to allow for an intuitive flow between each step of LULC change in the SWAT+ model. The interface allows for spatial selection and interactive editing of the HRU land uses. The SWAT+ model can also be run within LUCST and the visual analytics are incorporated to allow for easy scenario comparison. This section will explore in details how the individual LUCST GUI features are used and what purpose they serve.

3.1. Scenario management

A new scenario is created by clicking the 'Create New Scenario' button in the top right corner of the toolkit window. This opens a pop-up menu with an automatically generated scenario name (e.g., 'Scenario 1') that can be customised if desired. The new scenario is displayed alongside all other available scenarios in the Scenario Tab. When a scenario is selected, its name turns green (see Fig. 2), and that scenario's data is displayed. All the changes that are then made only affect the selected scenario.

3.2. Spatial selection map and land use change table

Three choices of a background map are available in LUCST, 'satellite', 'streets', and 'terrain', thus providing quick access to multiple methods of spatial identification. Three SWAT+ map layers are also available. The 'HRUs' and 'Channels' layers are essential for identification of HRUs and of the catchment drainage network. A sub-basins layer, although not essential (as its properties are never used by the application), is included to aid in the identification of separate drainage areas within a catchment. All layers can be turned off and on depending on the needs of the study. However, the 'HRUs' layer must be visible when making a selection. Landscape Unit (LSU) shapefiles were excluded from the interface to reduce the interface complexity. However, this layer may be added in subsequent LUCST versions. The map automatically centres to the coordinates of HRU 1. This ensures that, no matter the geographical location of the study catchment, it will appear in the map window when LUCST loads. Each layer's properties are accessible by clicking on the individual layer, the most relevant of which are 'channel', 'HRUS' and 'Landuse'. When a land use change is made, the HRU layers' 'Landuse' property is updated.

Clicking the lasso icon in the map window turns the cursor icon into a crosshair, indicating that the lasso tool is activated. The tool is used by clicking and dragging the cursor over an area of the map. Two selection options are available: contain and intersect. The contain method selects all HRUs which fall within the bounds of the lassoed area, whereas the intersect method only selects those HRUs where boundaries have been intersected by the cursor path. The intersect method is generally better suited for following a specific geographic feature (e.g., channel, road), whereas the contain method is better suited for making large selections (e.g., entire sub-basins). Selected HRUs become red and then revert to their original colour when a new selection is made. Spatial selection and, by extension, land use change is confined to the HRUs.

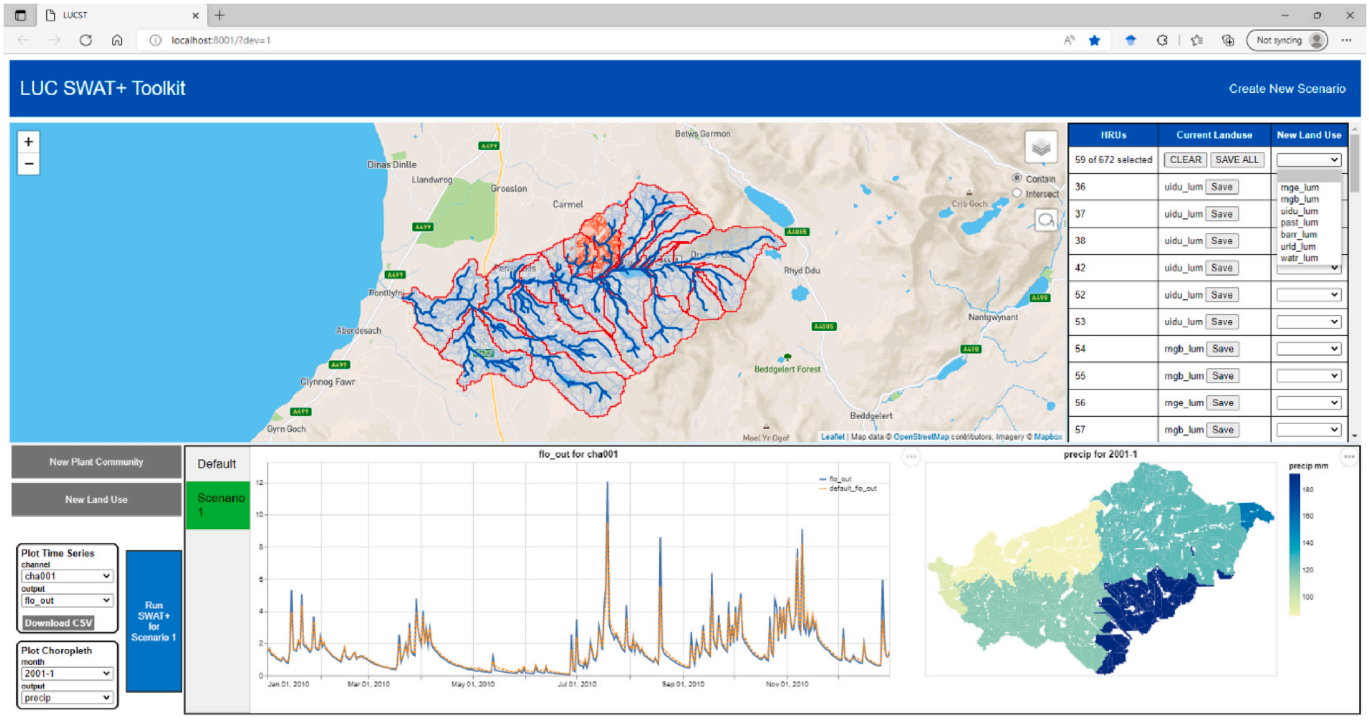

Fig. 2. Lucst interface.

Once a map selection is made, a Land Use Change Table is generated that displays the selected HRUs and their land use values. The land uses are displayed in the SWAT+ format to minimise operational disconnect between SWAT+ and LUCST. The entire selection can be cleared by pressing the 'CLEAR' button, although when a new selection is made the table is automatically re-populated. If a different scenario is selected, then the table is removed from the window until a new selection is made.

A drop-down list of all currently available land uses in the modelled catchment populates the tables 'New Land Use' column. A bulk LULC change can be made to all selected HRUs by choosing a land use in the top row and clicking the 'SAVE ALL' button. Alternatively, land uses of individual HRUs within the selection can be changed by choosing a land use in their row and clicking 'Save'. Values in the 'Current Landuse' column are updated when a change is made and an alert stating that a new 'hru-data.hru' file has been written indicates that the change has been saved. The change will not be saved if no land use has been selected.

3.3. New land use and plant community forms

Forms were decided upon as the most efficient and user-friendly way of gathering and handling the new plant community and land use parameters. Generally speaking, land uses in SWAT+ are centred around a plant community. Therefore, in order to make a new land use, a new plant community needs to be written (although there are some exceptions to this rule).

The input forms are opened by clicking on their corresponding button and are closed by clicking on the map. For both forms, clicking 'Make' writes the new item and clicking 'Reset' clears the form. The plant community name is automatically set as the chosen plant name with the suffix '_comm' (as per SWAT+ nomenclature for plant communities), although this can be changed if required. A 'standard' value automatically populates each New Plant Community input field to help simplify the process for non-technical users without specific plant community parameters in mind. However, it is advisable that some research is done for more accurate simulations. The land use 'Name' is automatically set to the 'Plant Name' from the plant community form with the suffix '_lum' (as per SWAT+ nomenclature for land use types). Where applicable, each input in the land use form has a drop-down list of the available parameter values. Both New Land Use and New Plant Community forms employ several checks (described in detail in section 2.2.3) to ensure that all SWAT+ formatting and rules are adhered to.

3.4. Model run and result visualisation

Clicking the 'Run SWAT+ for Scenario … ' button (updated with the current scenario name) initiates a SWAT+ run for the selected scenario. This process is indicated by a loading spinner in the visualisation window. Once the model has run, its outputs are displayed in the visualisation window which is designed to provide a quick and easy assessment of the impact of land use scenarios on catchment processes.

Having been designed primarily as a flood assessment tool, when 'flo_out' is loaded, flow out in m^3/s for the main channel is automatically plotted on the time series plot. In the 'Plot Time Series' control box, any output variable from 'channel_sd_day' can be selected from a drop-down list so that it can be plotted for any of the modelled channels (specific channel numbers can be identified by clicking the map layers). The plot title indicates which data is currently plotted. Two datasets are plotted on the time series: the selected data for the 'Default' scenario (orange dotted line) and the current scenario (blue solid line). This gives an instant indication of the impact of the land use change on channel output. The plot can be downloaded as a SVG or PNG file or, alternatively, the plotted data can be downloaded as a raw CSV file for further interrogation by clicking the 'Download CSV' button.

To complement the time series plot, a spatial choropleth plot is generated displaying 'hru_wb_mon' data (HRU water balance on a monthly time step). Precipitation for the first month of the model is displayed by default on the plot. In the 'Plot Choropleth' control box, any of the months of the model can be chosen and, like the time series plot, any of the 'hru_wb_mon' output variables can be chosen from the 'output' drop down list. The chosen output and month are displayed as the plot's title. The raw choropleth data is not downloadable because the data per HRU would bear little relevance without a spatial

Table 5
SUS survey scores and participant familiarity with SWAT+.

Participant Number	Familiarity with SWAT+	1. I think that I would like to use the application frequently.	2. I found the application unnecessarily complex.	3. I thought the application was easy to use.	4. I think that I would need the support of a technical person to be able to use this application.	5. I found the various functions in this application were well integrated.	6. I thought there was too much inconsistency in this application.	7. I would imagine that most people would learn to use this application very quickly.	8. I found the application very complicated to use.	9. I felt very confident using the application.	10. I needed to learn a lot of things before I could get going with this application.	SUS Score
1	Not Familiar	3	2	5	3	4	1	4	2	3	3	70
2	Aware of the Model	3	1	4	2	5	1	4	2	4	2	80
3	Familiar	4	1	5	1	5	1	4	1	5	1	95
4	Not Familiar	4	1	5	2	5	2	5	1	3	3	82.5
5	Not Familiar	5	1	5	2	5	1	5	1	5	2	95
6	Aware of the Model	3	1	3	4	5	2	4	2	5	2	72.5
7	Aware of the Model	3	1	4	2	5	2	4	2	4	4	72.5
8	Not Familiar	4	1	5	2	4	1	5	1	4	3	85
9	Aware of the Model	1	1	4	2	3	1	5	1	3	2	72.5
10	Aware of the Model	4	1	5	1	1	1	5	1	4	1	85
11	Aware of the Model	3	3	4	3	4	2	5	1	3	2	70
12	Not Familiar	3	2	5	2	5	2	5	1	3	3	77.5
												Average =79.8

representation of the catchment for reference. However, a SVG or PNG file of the plot can be downloaded.

3.5. Tooltips

A defining, and often overwhelming, feature of SWAT+ is the volume of files and consequent parameters and parameter values that are needed to properly implement land use changes. The approach taken to reduce the need for in-depth knowledge of these aspects of SWAT+ is the incorporation of a commonly used GUI feature known as the tooltip. A tooltip is a short description displayed on screen when the cursor is hovered over an interface element. Tooltips were added to LUCST elements where a deeper knowledge of a parameter, parameter value, or connection file could be beneficial to the task at hand. These elements include: the available new land use values in the Land Use Change Table, each input field and each item in the drop-down lists in the New Plant Community, and New Land Use Type forms.

3.6. System usability scale (SUS) survey

Bangor et al. (2009) compiled and compared over 2000 SUS surveys in over 200 studies for a range of user interface types and concluded that a mean score of around 72 constitutes 'good' and around 85 'Excellent'. From a total of 12 participants, LUCST achieved an average SUS score of 79.8 (Table 5), placing it firmly in the 'good' range of usability. Furthermore, Bangor et al. (2009) found 'first products' to score a mean of around 63, well below the first release of LUCST.

It was hypothesised that those users who had previous experience using SWAT+ and the challenges involved in making LULC changes would rate LUCST higher than non-SWAT+ users. Reinforcing this assumption, participant 3, who was most familiar with SWAT+, gave a SUS score of 95. Unfortunately, a lack of SWAT+ literate participants meant that no meaningful comparison could be made between SWAT+ users and non-users. For example, participant 5, who considered themselves to be 'Not Familiar' with the SWAT+ model, also gave an overall score of 95. However, the results from Table 5 clearly suggest that non-SWAT+ users did find the application to be useable.

Participants of the study were also asked two open-ended questions: 'Describe one positive feature about this application' and 'Describe one negative feature about this application'. These questions were designed to gain a deeper understanding of what features helped and hindered LUCST's usability.

Table 6 displays the positive comments. The interface's simplicity and user-friendliness were a recurring observation, commented on by nine out of twelve participants (2, 3, 5, 7, 8, 9,10, 11 and 12). Comments from four participants (4, 7, 10 and 12) suggest that LUCST can improve accessibility of SWAT+ for non-technical users. Participant 1 mentioned that LUCST had the potential for use in their own project despite being 'Not Familiar' with SWAT+, further suggesting its increased accessibility for non-technical users. Two participants (3, 5) positively commented on the result visualisation.

Table 7 displays the negative comments that eight out of twelve participants provided for this section. Out of the participants who responded, five (2, 5, 6, 7 and 12) suggested negative features relating to the complexity of SWAT+ itself as opposed to the LUCST user interface. Two of these participants (5 and 6) directly mention the technicality of the SWAT+ language and specific 'habitat' (assumed to mean land use and plant communities) naming. Only participant 9 negatively commented on the interface.

Table 8 displays the results of the usability study's feature analysis section. The participants ranked each feature on a scale of 0–4, giving a maximum possible score of 48 (12 x 4). The score, as a percentage of the maximum, was calculated. The 'Land Use Change Table' scored the highest with 83%. 'HRU selection' and 'Output Visualisation' came joint second with 81%. The mechanism for adding new plant communities and land use types scored lowest with 79%, which suggests that it was

Table 6
Usability Study - positive comments.

Participant Number	Describe one positive feature about this application
1	"The application has potential for use with my own project"
2	"It integrates the SWAT functionality very well and provides you with a simple interface for changing the land use of multiple HRU's within a catchment while also maintaining the useful complexity of the base SWAT programme"
3	"Very simple to use interface which makes is easy to implement changes and see the impact"
4	"More accessible than a normal model"
5	"Easy to use and graph easily illustrates the changes"
6	"Automated CSV download link for each channel/variable selected"
7	"It was very accessible to non-users and not difficult to understand"
8	"The positive feature about this application is that it is extremely user-friendly"
9	"The interface is easy to use"
10	"It is useful and well designed, with clever UX. To most users, particularly non-technical users, the interface is the application - and this has been very well done. Consider commercialising this!"
11	"Not very complicated"
12	"The use of its function and presentation of the results is intuitive even for myself who do not have any previous experience with SWAT software"

Table 7
Usability Study - negative comments.

Participant Number	Describe one negative feature about this application
1	No response
2	"The complexity of the SWAT model, although incredibly useful to proficient users that can harness the powerful tools it provides, might be a little overwhelming and confusing to new users, especially if they are less IT orientated. The added functionality of the LUCST programme and the inherent complexity and learning curve adds to this, which is what makes the usefulness of the walkthrough document crucial to it's success."
3	"Can't think of any"
4	No response
5	"Name of habitats difficult to understand"
6	"Some language was technical to the untrained user"
7	"There are a lot of parameters that may take time to process"
8	"I cannot find any negative feature, the application is quite helpful for hydrologist"
9	"The buttons don't quite fit on one screen. The user needs to scroll up and down."
10	No response
11	No response
12	"There are too many alternatives for different parameters e.g., land use and this can be quite overwhelming for somebody who uses the application for the first time"

perceived to be the least impressive feature.

4. Discussion

4.1. Integration into the SWAT+ environment

The restructuring of SWAT to SWAT+ was in part done to foster and encourage new innovations by external researchers (Bieger et al., 2017). There are currently various SWAT+ add-ons and supporting applications developed by different user-groups available publicly. Some examples include SWAT+ Toolbox (Chawanda, 2022), IPEAT+ (Yen et al., 2019), SWAT+ AW (Chawanda et al., 2020), and SWAT2lake (Molina-Navarro et al., 2018). Although these add-ons and applications all help with various tasks, they all have the common goal of making the running of SWAT+, and its associated tasks, simpler (Yen et al., 2016, 2019). This is also the fundamental goal of LUCST in relation to LULC change assessment. LUCST will add to the growing arsenal of SWAT+ add-ons and can either be incorporated as a key component of SWAT+ studies or as an additional investigation tool with little need for prior planning. By accepting a calibrated catchment as its input data, LUCST slots perfectly behind the calibration tool 'SWAT+ Toolbox' in the SWAT + workflow.

Table 8
Usability Study -Feature Analysis scores.

	Participant Number	HRU Selection	Land Use Edit Table	New Land Use and Plant Community Forms	Output Visualisation
	1	3	3	3	4
	2	4	4	3	4
	3	3	4	3	3
	4	3	3	4	4
	5	4	4	3	4
	6	3	3	4	3
	7	3	2	2	2
	8	3	4	4	3
	9	2	3	3	2
	10	4	3	3	4
	11	3	3	3	3
	12	4	4	3	3
Total Score/48		39	40	38	39
Percentage		81%	83%	79%	81%

4.2. Improvements on current methods by feature

4.2.1. Scenario management

LUCST removes the need for manual management of scenario folders. Through this application, safety checks are in place to ensure that the integrity of the 'Default' scenario is maintained. In contrast, when making changes through the SWAT+ editor or manually in the SWAT+ text files, there are no such barriers. LUCST's Scenarios Tab enables a frictionless transition between the scenarios, whereas current methods require the user to traverse multiple platforms, folders, and files. With the system applied by LUCST at the click of a button, all data relevant to LULC change impact assessment is displayed in one window for the chosen scenario. This reduces both the necessary knowledge of SWAT+ files and time it takes to make multi-scenario LULC change impact assessments. By guaranteeing no changes are made to the 'Default' scenario, LUCST ensures that a LULC change study will yield meaningful results.

4.2.2. HRU selection and Land use change

The HRU shape files produced during catchment set-up in QSWAT+ contain only the attributes of the 'Default' scenario. LUCST improves on this by updating map layers with land use attributes from the current scenario. The updating of layer attributes displays changes within the catchment and removes the need for interpretation of 'hru-data.hru' in conjunction with QGIS. Additionally, LUCST provides background map options to aid in spatial referencing during the HRU selection process, whereas in QGIS, background maps require importing.

The method of HRU selection in QGIS and the one adopted by LUCST are very similar. In both, selections are made by using the cursor to define an area of the catchment to select the HRUS within it. However, the 'contain' or 'Intersect' methods offered by LUCST are tailored to suit specific selection requirements depending on the needs of the study. HRU selection scored 81% in the feature analysis section of the usability study, suggesting that it is well received by possible end-users.

The Land Use Change Table scored highest (83%) in the feature analysis section of the usability study. Automatically populating the

Land Use Change Table from a selection is no different from QGIS automatically populating an attribute table from selected layers. However, in QGIS, this is where the automation ends. The HRU IDs then need to be identified from the attribute table and compiled into a list which can be referred to when manually editing the 'hru-data.hru' file. Available land uses need to be identified from 'landuse.lum' to ensure only viable land use changes are made, adding to the workload and data management requirements. LUCST completely bypasses all these manual interactions, providing all relevant data within one interface. While in previous methods it is possible that hundreds of 'lu_mgt' values would need to be manually changed individually, LUCST achieves the same result with the selection of a land use code (from the drop-down list) and the click of a button ('SAVE ALL' or 'Save').

4.2.3. New Land use and plant types

Within LUCST, it is hard to mitigate for the number of technical parameters that make up both plant communities and land uses. This quantity and technicality of parameters is an inherent characteristic of complex process-based hydrological models (Yang et al., 2000; Devia et al., 2015). In general, a larger number of parameters, although adding to the complexity, improve the mathematical representation of the catchment (Yang et al., 2000; Devia et al., 2015). Although the input forms do nothing to reduce the number of parameters needed, they help organise (with the aid of tools and pointers) the building of a land use or plant community in an intuitive way. Unfortunately, the nature of SWAT+ means that at least some technical understanding of the model is needed to generate new plant communities and land uses to accurately represent their real-life counterparts. This complexity was reflected in the feedback from the usability study where the forms scored lowest of all the features (79%). The largest group of negative comments referred to the complexity of the SWAT+ model and its nomenclature as the most negative feature of the application.

LUCST automatically locates each relevant connecting file and extracts all parameter value names, thereby reducing the need for interaction within the 'TxtInOut' directory. The names are presented in drop-down lists in the input forms and, where applicable, the list items are anchored with their SWAT+ descriptions as tooltips. All input fields are labelled with the full parameter name as opposed to their SWAT+ code (e.g., Manning's N instead of ov_mann) and also anchored with their SWAT + description and connecting file name. Additionally, checks ensuring all SWAT+ formats and rules are adhered to that are employed by LUCST (section 2.2.3) do not exist when manually writing in the SWAT+ text files.

4.2.4. Output Visualisation

Clear visualisation is key to communicating results effectively (Van Wijk, 2005) and was therefore a key element in LUCST's development. The large quantity of data outputted by SWAT+ (files and output parameters for each catchment channel and HRU) can be overwhelming and make manual extraction of the correct data a time-consuming and cumbersome task. The workload is then multiplied when it is necessary to plot the results of multiple scenarios for output comparison. LUCST locates both the channel file (channel_sd_day) and HRU water balance file (hru_wb_mon) automatically and then filters and plots the chosen data instantaneously. The channel data is plotted alongside the default scenario for instant result comparison. A time series plot was chosen as one of the simplest plots for human interpretation of temporal data (Dunn, 2019). The ready-sorted channel data can also be downloaded for deeper interrogation if required.

Having the result visualisation incorporated within the LUCST interface in one window means that specific channel names can be identified from the desired catchment location (by clicking on the map layer) and selected for plotting. In previous methods, the easiest way of associating a channel with a spatial area was through QGIS attribute tables. LUCST also incorporates visualisation of the spatial HRU water balance data to complement the channel output data. This enables easy association of channel output events to the catchment water balance, e.g., high peak flows with high precipitation.

4.3. Improvements on current methods as a whole

Although each feature provides its own improvements to the individual stages of LULC change in SWAT+, improvements to the process as a whole need to be considered to fully understand the benefits of LUCST. At first glance, the two significant improvements that LUCST makes are to increase the speed and reduce the complexity of making LULC change impact assessments. These two elements are non-mutually exclusive and feed into one another to help improve the overall accessibility of the SWAT+ model as a LULC change impact assessment tool (Fig. 3). That is the primary accomplishment of LUCST.

4.3.1. Reduced complexity

Task complexity negatively impacts performance and behaviour, which is something that needs to be seriously considered in system design (Liu and Li, 2012). Furthermore, complexity is assumed to influence mental workload (Jacko and Ward 1996), thereby affecting performance (Valdeza et al., 2015). By providing checks and helpful features as well as automating specific tasks in one user-friendly interface, LUCST reduces the complexity of manual LULC change impact assessments.

4.3.1.1. Reduced need for technical knowledge. The need for technical knowledge is a major barrier for new users when it comes to assessing the impact of LULC change in SWAT+. LUCST removes some of this complexity: firstly by automatically locating and uploading files essential to the task at hand (e.g., 'channel_sd_day' for result visualisation), and secondly by reducing the need for knowledge of inter-file connections. The application does this by locating and providing all parameter options in drop-down lists where applicable. Tooltips provide deeper descriptions of complex elements as and when they are needed. As discussed later in this section, the removal of cross platform interaction also reduces the need for technical knowledge of multiple programmes.

4.3.1.2. Reduced human error. Manually implementing changes to a SWAT+ catchment allows room for human error, e.g., changing the land use of the wrong HRU, using parameter codes not available in the catchment, or by writing data in the wrong format. As workloads increase, repetition can lead to tedium, confusion, and increased chances of human errors (Reason, 1990). Whilst it is true that an ill-informed land use change or new plant type can be made through the LUCST interface, the data is always written in the correct SWAT+ format to the exact user specification. If an undesired change is made, the automation introduced by the application means that these changes are easily reversable.

4.3.1.3. Reduced need for cross platform interaction. Currently, all methods of LULC change assessment using SWAT+ involve the

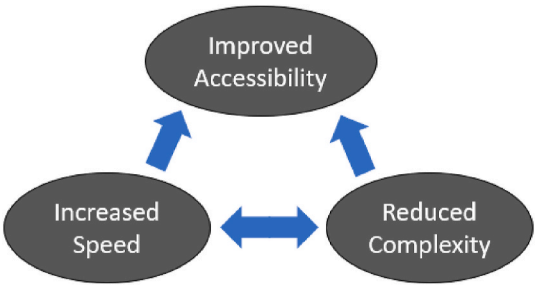

Fig. 3. Conceptual relationship between application Speed, Complexity and Accessibility.

integration and use of multiple platforms: QGIS, QSWAT+, multiple text files (along with input/output SWAT+ documentation), SWAT + Editor and a CSV reader (like Microsoft Excel). This results in the need for trained, technically competent SWAT+ users with a good understanding of these platforms and how they interact to implement an LULC change study. Even for technically competent users, swapping between programmes, text files and platforms can become cumbersome, tedious, and lead to confusion and mistakes. The inherent complexities of SWAT+ further run the risk of alienating non-technical users.

LUCST provides all the steps of LULC change assessment on a single platform. Each step of the process after initial catchment set-up and calibration can be implemented through the interface. Not only does this add to the user experience, it, along with the automation introduced by each feature, also vastly reduces the time needed to study LULC change scenarios. The toolkit provides an array of features, all compiled in one application, thereby reducing the level of expertise and data management needed to make fast and accurate assessments of the impact of LULC change on catchment processes.

4.3.2. Increased process speed

In addition to the complexity, the time it takes to make LULC change impact assessments in SWAT+ is another limiting factor for hydrological studies and can lead to the neglect of certain land use scenarios. By automating specific tasks, which otherwise would be done manually, LUCST vastly reduces the time it takes to conduct LULC studies using the SWAT+ model, thereby increasing the potential for initial and further investigation.

As mentioned in Section 4.3.1, a major time saver generated by LUCST is the compilation of all LULC change features within a single application. Making complex changes to the model manually often involves swapping between files and programmes several times (to check parameters, HRUs, channels, help documentations etc.) with the possibility of significantly increasing the length of time taken to make a study. LUCST provides all the files, parameters, descriptions, and features in one application. The primary time saving feature of LUCST is the automation of file writing and output uploading. Automation of previously manual tasks allows LULC change scenarios to be constructed and their outputs compared in a relatively short period of time. This enables the construction and comparison of more scenarios per study as well as the possibility of adding LULC change assessments to studies where previously the option would have been dismissed due to time constraints.

4.3.3. Improved accessibility

LUCST increases the speed and simplicity of making LULC change impact assessments in SWAT+, which in turn increases the model's accessibility. The results of the preliminary usability study backed up this observation, suggesting an improved accessibility for non-SWAT+ users. With LUCST, for the first time, SWAT+ can be used for 'on-the-go' LULC change studies without the need for meticulous planning, data management, or extensive technical knowledge. To this end, LUCST will not only help make the model more accessible to non-SWAT+ users but also allow technical users to conduct studies in a much more time effective and convenient manner than previous methods.

4.4. Facilitating hydrological investigations

Since the rise in environmental awareness at the end of the last century, the need for a good understanding of the impacts of land use change on the hydrological response of catchments has become increasingly apparent (Grayson and Blöschl, 2001). SWAT+, as an internationally recognised hydrological model that stands up to scientific scrutiny (Arnold and Fohrer, 2005; Gassman et al., 2007; Ullrich and Volk, 2009), is the perfect tool to provide quantifiable evidence of the hydrological impact of different land uses. LUCST output accuracy depends on: the SWAT+ model, the accuracy of the input data at catchment set-up, and the accuracy of model calibration (Gassman et al., 2014), all of which are independent of the toolkit's design. As a result, use of the application does not directly achieve greater model accuracy. However, LUCST helps fill a gap in the research as it provides a platform for more research to be conducted at greater speed. By increasing model accessibility to a wider range of user groups, the likelihood of proper hydrological assessments being made will increase and likely have a positive knock-on effect on catchment management.

5. Conclusion

Two main factors influence the hydrological response of catchments: climate, and land use. Both climate change and land use change are impacting catchment processes globally. With no short-term possibility of reversing the anthropogenic impact on the atmosphere and climate, land must be managed appropriately to mitigate the effects of contemporary climate conditions. One of the biggest obstacles to successful land management is a lack of scientific understanding and quantifiable evidence of its effects. Therefore, it is imperative that local hydrological responses and the impact the LULC change will have on those responses are properly understood to help make informed catchment management decisions. To improve understanding of local and regional catchment processes, decision makers need access to tools which produce quantifiable and scientifically rigorous results.

In this paper, LUCST has been introduced as one of the only tools of its type that can streamline LULC change assessment in SWAT+. By utilising SWAT+ as its hydrological modelling engine, it was possible to 'piggyback' on the well laid foundations of SWAT+ in terms of its user group, workflow, and wealth of scientifically accredited studies. Although the list of possible additional functions is long, the toolkit has met the studies original aim of making LULC change assessment easier. In its current stage of development, the improvements LUCST has introduced to LULC change impact assessment in SWAT+ have shown that it has great promise as a tool to aid in catchment management.

Software availability

Software name: LUCST (Land Use Change SWAT+ Toolkit)

Developers: Alexander Rigby (rigbya96@gmail.com); Peter Butcher (p.butcher@bangor.ac.uk)

Year of first release: 2021.

Hardware requirements: PC.

Software Requirements: Windows 10; NPM >8.1.2; NodeJS >14.15.4; Python 3.9.7; SWAT+ rev60.5.2_64rel.exe.

Program language: JavaScript, CSS, HTML.

Program size: 31.3 MB.

Availability: https://github.com/alexrigby/LUCST.git (open-source)

Documentation: Full step-by-step installation, setup, and interface instructions are available in the 'documentation' folder within the GitHub package. LUCST runs SWAT+ rev60.5.2_64rel.exe. Therefore, some features may not work as expected with catchments modelled using other versions of SWAT+.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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