SOFTWARE FOR COMPLEX PROCESS AUTOMATION AND STAKEHOLDER RELATIONSHIP: STATE-OF-ART IN HYDROGIS TOOL FOR URBAN FLOOD MANAGEMENT

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Abstract- To make sustainable decisions in policy making/ public decision making, the assisting software should provide sustainable options. This is very important in urban flood management, due to the involvement of number of stakeholder groups. In order to develop such software, a software development effort needs to realise the basic requirements of sustainable decision making, which need more research. The present work attempts to study the available researches for sustainable decision making process in urban flood management and analyse according to the software development profession. The present work utilises a HydroGIS tool development effort, which was developed for urban flood management, to review the literature findings. The study found the importance of understanding the complex-process integration with recipient stakeholders for the development of a sustainable decision making software.

Keywords- Sustainable software, Recipient Stakeholders, HydroGIS tool, Urban Flood Management

I. INTRODUCTION

A. Project Stakeholder Management

Stakeholder Management is the latest knowledge area (KA) of the Software Project Management. The requirements of the stakeholders may change with the project development and such requirement change may lead to make drastic decision of shutting down the project. Therefore, a close monitoring of the project stakeholders is a sine-quo-non in today's project management. However, once the required software is produced to the users/clients, then it considers enclosure (PMBOK® Guide – Sixth Edition, 2017; SEBoK contributors, 2015).

B. Software Sustainability and Recipient Stakeholders

Nevertheless, if the produced software does not assist stakeholders to arrive at a sustainable decision, the software becomes a useless tool to the stakeholders even if it provides technically accurate and feasible answers. Specially, if such decision is made by the governing bodies/ policy makers and negatively affecting the general public, the decision makers tend to make a fresh decision violating the technical guidelines to favour of general public for reduce the resistance. Then these recipient stakeholders who are not direct users of the software but effected through the result of the system, directly influence the sustainability of the software. It has realised that the software developers should identify and provide the facility to users of the system to incorporate recipient stakeholders' requirements whilst the decision making process. At present practise the software developers gather recipient stakeholders' requirements through the end-users who are not capable to clearly express their own requirements too (Becker et al., 2015; Mysiak, Giupponi, & Rosato, 2005; Penzenstadler, Femmer, & Richardson, 2013; Venters et al., 2018).

C. The Multiple Complex Processes Automation

In other view, the decision making process in government/ national scale may contain different complex processes. These complex processes lay on different expert areas which may far away from the software developers' capabilities. Then the code development and testing of such software become more difficult task. Further, when such individual processes required to be changed to satisfy the recipient stakeholders, the developers need to have a clear understanding about process as well as communication between processes and stakeholders.

D. Urban Flood Management

The decision making process in the urban flood management is a one of the prominent scenarios which urges better recipient stakeholder management facility. To arrive to an optimum flood management decision, the governing authorities utilised experts from different areas such as hydrology, town planning and finance. Then they can develop hydrologically accurate, economical plan which match with the existing town plan. But when install the plan on the ground, citizen start to resisting due to interruption to their social, economical and financial practises. Then the governing bodies have to either stop the project or progress with the project align to the citizens, but violating town planning, economical or hydrological decisions. Therefore, the decision support system needs to provide the facility to optimise the solution with incorporating the citizens' requirements at decision making level (Gray, Paolisso, Jordan, & Gray, 2017; Voinov et al., 2016; Weiler & Beven, 2015).

Therefore, when develop such software, developers need to identify (1) recipient stakeholders, their requirements against the scientific decisions, tread offs of both recipient stakeholders and decisions makers and (2) Interaction between different complex processes. Nevertheless, no study has found which analysing both the complex processes handling and recipient stakeholder management on the data and processes sharing perspective.

E. Aim

Then, the aim of the present work is to identify and review the state-of-art in data and process relations between users, recipient stakeholders and different complex processes using a case study of urban flood managing HydroGIS.

II. LITRETURE REVIEW

A. Case Study: Urban Flood Management HydroGIS Tool

As the case study, it selected the stakeholders and processes described in the work of Pradeep and Wijesekera (2011, 2012). Accordingly, it has developed a software which assist local government technical officers (TO) to grant the permission to citizens to carryout land modifications, considering the contribution to the urban flood due modifications. If the required modification is effect on the flood, the TO is allowed to reach a solution with both/ either readjust the modifications and/or incorporate a detention tank to minimise the contribution. For this work, the software developers had to share the data with GIS and Hydrology processes and allow end user (TO at local authority) to optimise the solution by negotiating with recipient stakeholders, the citizens.

B. User roles whilst Integrating Complex Processes in HydroGIS Tool

The main processes involved in the HydroGIS tool are hydrology process and GIS processes. Due to the requirement of automating a hydrological calculation sequence using GIS capabilities, developer has to identify how to integrate GIS and hydrological processes.

At the early stages in 1990s the hydrological calculations and GIS integration carried out using two approaches namely (1) loosely coupling and (2) tightly coupling (Figure 1). In loose coupling approach, hydrological calculations process gets the required parameter values from GIS software processes, manually. Then when it required displaying the results on maps, it has to reproduce the data to GIS. In tightly coupling approach, hydrological process and GIS software are sharing the information required by both hydrology and GIS processes, through software codes.

When formulating these approaches the user involvement made an influence to develop two approaches. The loosely coupling approach is a researcher-oriented which needs more engineering knowledge in bolting hydrology and GIS. The tightly coupling approach needs to facilitate less technical users to perform hydro calculations using GIS environment.(Stuart & Stocks, 1993)

With the development of GIS technology over the time, the attention had being paid to use the GIS capabilities in data analysing and accurate data representation in environmental modelling. Sui and Maggio (1999) describe the integration approaches in four different ways as shown in the Figure 2. The added new approaches were integrating the Hydrology/GIS calculation steps into Hydrology/GIS software tool. It can observe that behaviour and responsibilities of the users in integration of hydrology modelling and GIS capabilities become a reason to develop four different approaches. However the user profiles for each approach is doubtful as shown in the Table 1. When analysing, it can see that the user is a modeller as well as a software developer.

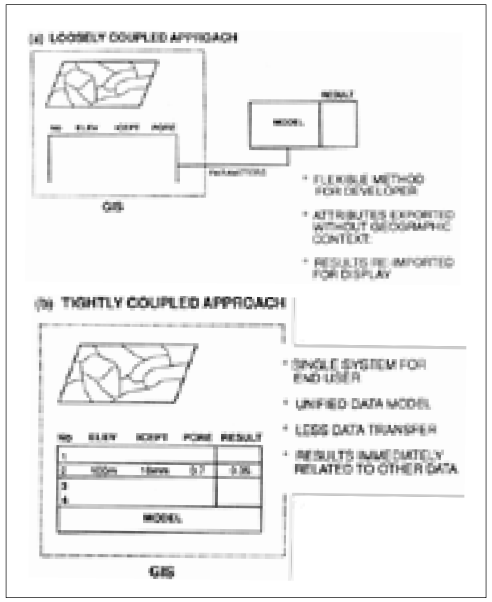

Figure 1. Two Alternative ways of linking a model to a GIS
Source : (Stuart & Stocks, 1993)

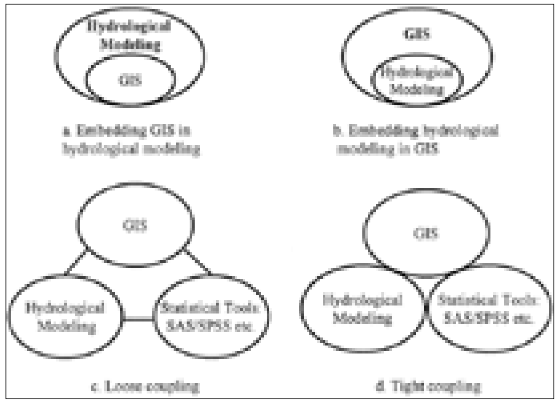

Figure 2. Integrating GIS with hydrological modelling
Source: (Sui & Maggio, 1999)

Further to the user roles in integration, Huang and Jiang (2002) have considered integrating data and/or functions in GIS and hydrology models and summarised the four approaches to three approaches; loose coupling, tight coupling and full coupling as shown in the Figure 3. However the full coupling may either development of software codes to hydrology model processes within the GIS software or development of hydro modelling software with GIS capabilities (Alcaraz, Vázquez-Suñé, Velasco, & Criollo, 2017). Then this full coupling can be considered as "Embedding".

Table 1. User role in Hydro GIS integration approaches – Author Review

Approach	User profile	Disadvantage
Embedding GIS functionalities into hydrological modelling software.	Users are Hydrological modellers, who need GIS as a mapping tool. The requirement of programming skill upgrade the hydro modeller to SW developer/hydro modeller	As hydrological modelling software do not have GIS functionalities, then an intensive programming effort need.
Embedding hydrological modelling in to GIS software.	Unclear whether the hydro modeller or GIS modeller but can be described as GIS software users. Users use inbuilt hydro models in GIS software	GIS functionalities are satisfied. But the hydro model validation is doubtful
Loose coupling	Hydro and GIS software connection carried out by data exchange with less programming. Hence most GIS users and Hydro modellers can use this approach	Data conversion becomes a responsibility of users.
Tight coupling	Users use scripting or general programming language within the GIS to automate the hydro model. Hence user has to be a highly technical person.	Users are allowed to customize user routing, but need to consider the spatial data structure.

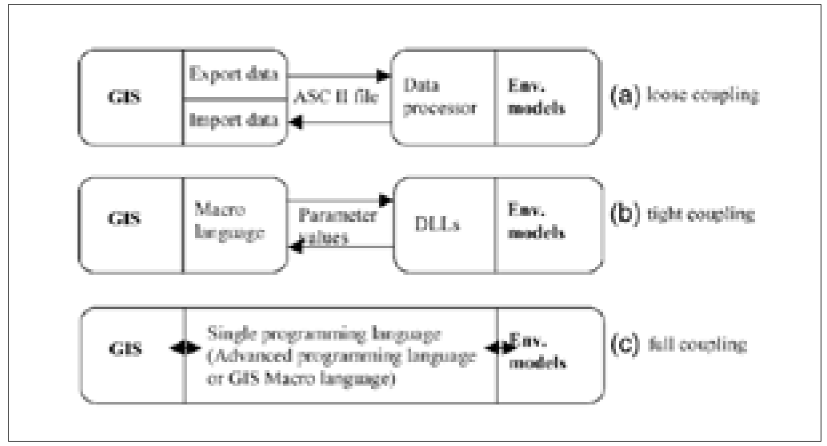

Figure 3. Different approaches to the coupling of environmental models with GIS
Source: (Huang & Jiang, 2002)

C. Stakeholder factor of HydroGIS tool

When consider the different user roles involved in the water resource management decision making in hydro-GIS integrated tool development, an ambiguity arises. To clarify the users, it considered the influential participants in water resource management decision making. Through the outline study, it found a history long discussion about the public participation in decision making which does not considered in Hydro-GIS integration. However public participants are a key interest group of users. The Arnstein (1969) discussion on the different level of engagement of participation of public in decision making which varying from manipulation (non-participation) to citizen-control (fully managerial power), added new knowledge to all decision making disciplines.

In the field of water management, public participation is considered as a key principle. Pioneering Dublin Statement (1992), Water Frameworks Directive (EC, 2000) and the Hague Declaration (2000) recognized the requirement of involvement of stakeholders in each level of water decision making. However application of this principle remained problematic due to decision makers (government) unwilling to participate public, limited/absent response from the public, low quality response from public and difficulty of conclude the decision making with consistency due to expenditure issues, information hiding from each other or lack of time (Mostert, 2003). As these difficulties public participation become a real challenge that need to manage carefully to arrive to a sustainable water management solution.

In incorporating the public to the water management processes, Henriksen et al., (2009) attempted to involve stakeholders to water resource modelling. They have identified 3 stakeholder groups based on the influence on decision making such as (1) Consultation (opportunity to comment /views), (2) Interaction (allow to advice but decision makers have power to accept or reject) and (3) Engagement (negotiate and engage in trade-offs with traditional power holders). Further they involve the users in determination of the requirement at model study plan and review steps of all the modules such as data and conceptualization, model setup, calibration & validation, simulation and evaluation. However the user role is around "Interaction". This study shows the academic maturity of stakeholder study in water resource management.

However, researches use these stakeholders involvement in hydrology modelling when the watersheds are spread over different nations and cultures. Comair et al. (2014) work is one of such example which stakeholder engagement in water resource management in global context exceeding the trans-boundaries. Nevertheless, the HydroGIS integration is not considered when integrating stakeholders in decision making process.

Table 2. Summary of the User role in HydroGIS integration approaches

Approach	Process integration by[1]	Data Integration through[2]	Author's Review	
			Knowledge required	User & Role
Loose coupling	Users	Files sharing	Spatial Data formats, inputs preparation and output interpretation	Modeller and decision maker: *Use hydro/GIS software for decision making. Data preparation and sharing between processes are done by themselves*
Tight coupling	Users and software codes	Inter software Parameter passing	Software coding knowledge, understand the architecture of both software	Software Developer: *Integrate and develop a system with data preparation and sharing facility between different processes* Modeller/ decision maker: *use the developed system*
Embedding GIS in hydro model	Users using Hydrological Software	Parameter passing within the modules in the software	In-depth knowledge in GIS function automation	
Embedding hydro model in GIS	Users using GIS Software		In-depth knowledge in Hydrology model automation	

[1]Integration by Stuart and Stocks(1993) and Sui and Maggio (1999)
[2]Integration by Huang and Jiang(2002)

III. RESULT AND ANALYSIS

A. *Results for HydroGIS Tool User roles whilst Integrating Complex Processes in HydroGIS Tool*

Through literatures it can identify four classifications for integrating which can summarize into the three classifications. However integration is setting up for sequential process of GIS and hydrological functionalities which is verified by the modellers. But the user role in this process is unclear. As well all the integration attempts were tried to share the model steps complexities with the different candidate software, such as with GIS software, statistical packages and hydrological software. Author reviewed that the integration is conceptually discussing how this software interacts to perform to get an output from hydrological model. This can be described under two different concepts.

Process integration concept: When carrying out a HydroGIS calculation, the integration can be divided in to four approaches based on the software and user involvement in carrying out processes (Figure 2).

Data integration concept: Aforesaid process can be automated (use software coding to handle the sequence) or can be handle manually (processes carryout using different software by users). Then the data handling responsibility has to be solved and it became an important consideration in integrating.

The data integration classification is based on the data sharing with the hydrology model and GIS software whilst the calculation process. Three approaches of data sharing can be observed when review the literatures, (1) User generates required data using either GIS or hydrological modelling software and share with the counterpart software (2) User operates either GIS or hydrological software, the data sharing is done through intercommunication between software itself (3) User handles the processes steps in a single software, then software perform all the functionalities and pass the data between hydrology and GIS through the developed codes itself. Therefore the two approaches of embedding hydrology model and GIS which shown in Figure 2 (a and b parts), are considered as a single approach as Full coupling in Figure 3.

User knowledge and Role: Foresaid different integrations are based on the approaches made to perform a hydrological model to arrive to a water management decision. Within these processes, users have to use GIS and Hydrology modelling tools. But the level of knowledge required to handle is varying from software development knowledge to tool operating knowledge. Therefore a doubt arises when clarifying the term "user" in the integration. Then a set of users and their roles were reviewed and formulated based on the knowledge requirement in integration. Accordingly, Table 2.0 describes the user roles based on their knowledge and engagement in decision making process.

Then, when study the created user and their roles, it's clear that the integration attempts were made without considering the model development and decision making processes. If the decision making team has all the knowledge such as Hydrology modelling, software development, data management and GIS software handling then integration of hydro-GIS can follow any approach. Nevertheless, always decision making teams consist governing authorities and modellers. Then if the "modeller" carryout all these integration and provides the information required, the decision maker has only to reach a sustainable water management decisions. But to reach the sustainable decision it required the stakeholders' ideas to be considered from model development to decision making. However literature proved that the GIS is a better option to fulfil the communication requirement of this kind of relation. (Jessel and Jacobs, 2005). So incorporating recipient stakeholder is an advanced study than HydroGIS integration approaches. It has to study how different users and their roles interacting with GIS and Hydrology when model development for water resource management.

B. *Results for Stakeholder factor of HydroGIS tool*

When consider the both the Hydro-GIS integration and stakeholder-hydro modelling relation, the user role of the stakeholders became a problem. The present work review that, if the user role in the process of water management can be solved, then it facilitates to select the most suited hydro-GIS integration approach. Then when solve the user roles it needs to define a clear demarcation of the responsibilities in integration. The responsibility of hydro-GIS integration activities can be only defined among the different stakeholders if it clearly identifies the users' roles in each and every integration point of water resource decision making process.

Therefore in Hydro and GIS integration, the users who are working with the model are called "Modellers". In stakeholder and Hydro Modelling relation the users are the general public and decision makers. Then basically it can identify three different users in the HydroGIS assisted water resource management, such as (1) Modellers (2) Decision Makers and (3) General Public / Recipient stakeholders.

Then integration of processes and stakeholders according to the present literatures is shown in the Figure 4. Description of the processes and data in the figure is shown in the Table 3.

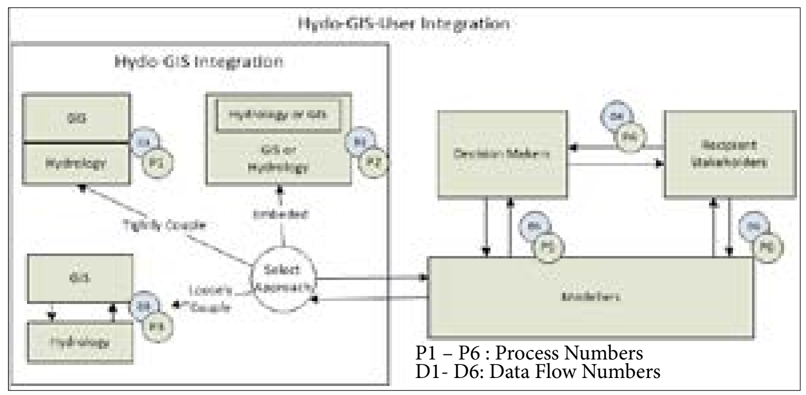

Figure 3. Hydro-GIS-User Integration

Table 3. Involvement of Users in different integration approaches

Process / Data	Description	Modeller	Recipient Stakeholder	Decision Maker
P1/D1	Tight coupling of processes and data	integrate the process and data via coding	No description	Provides rules and regulation to modeller
P2/D2	Embedded processes and data	Embedded one system to other using coding		
P3/D3	Loosely couple processes and data	manually integrate the process and data		
P4/D4	Coupling / embedding decision makers and stakeholders	N/A	1. Either one will adhere to other's requirement / rules 2. Requirements and rules are matching each others 3. Both can negotiate to a conclusion	
P5/D5	Coupling / embedding decision makers and modellers	Integrate hydro and GIS based on decision maker's rules	N/A	Provides rules and regulation
P6/D6	Coupling / embedding modellers and stakeholders	1. Either one will adhere to other's requirement / rules 2. Requirements and rules are matching each others 3. Both can negotiate to a conclusion		N/A

Note: Data and Process integration is shown from D1 to D3 and P1 to P3. D4 to D6 and P4 to P6 show the data and process integration between different users.

Hydo-GIS-User Integration

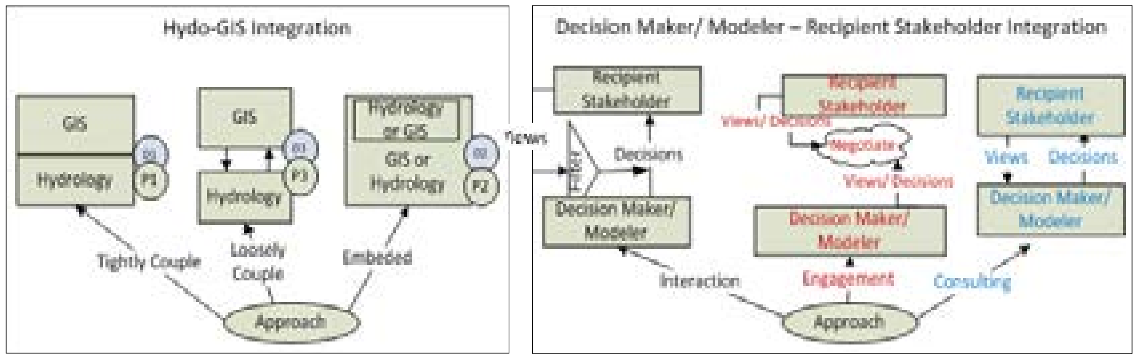

Figure 4. Final Hydro-GIS-Stakeholder integration scheme

Table 4. Stakeholders of HydroGIS tool

Stakeholder	Description	Example
Recipient Stakeholders	The general public who get the benefits/suffers from the decision made	Land owners, citizens
Regulating Stakeholders	The person/s who take decision in development	Local Authority such as Urban council
Institutional Stakeholders	The individuals who technically develop and process the decision making process	Hydro and GIS modellers, tool operators & developers

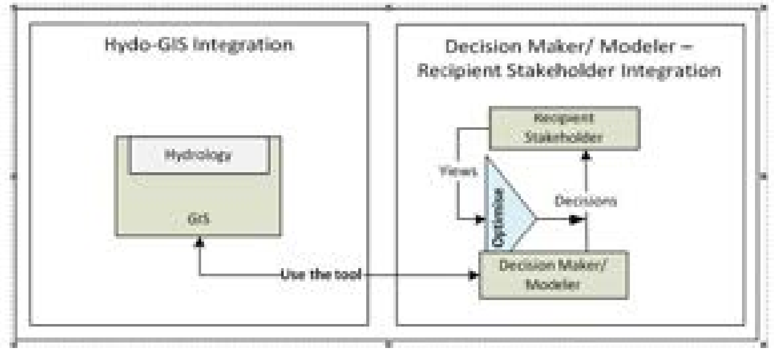

Figure 5. Hydro-GIS-Stakeholder integration schema for Automation

C. Hydro-GIS-User Integration

According to the results it has realised that, recipient stakeholder and decision maker integration has different approaches. Hence in Hydro-GIS- Stakeholder integration, there are two different approaches are to be selected. Then after incorporating the different levels of involvement in decision making, the final picture of the Hydro-GIS-Stakeholder integration is as shown in Figure 4. In this view, the hydrology/GIS modellers are disappeared, but it can identify, for selection of approaches and assisting in stakeholder integration, there should be another group of stakeholders.

Then this additional stakeholder is a group of people which consists of modellers, tool operators and if there is automation, software developers. Therefore the final stakeholders can be grouped and identified as shown in the Table 4.

D. Automating Hydro-GIS-User Integration

Finally the present works analysis the integration requirement of automating the entire processes which can be run by non-technical decision makers/tool operators. Whilst this automation, author realised that the optimization of the recipient stakeholders' requirement can be achieved through "Interaction" option of stakeholder relation. As well considering the well-developed GIS software industry, the present work read the situation to select embedding the Hydrology model in to GIS software as the best option. Then the most suited hydrology-GIS-Stakeholder integration is shown in the Figure 5.

V. DISCUSSION

The present work considers the suited integration scheme for hydro-GIS-stakeholder should be similar to the schema shown in in Figure 5, when automating a hydro-GIS process which is to be utilised in urban flood management decision making with recipient stakeholder's requirements optimization.

The integration consists of two different areas which are; (1) Hydro model-GIS software integration; and based on the maturity of GIS software industry, the work proposed to integrate hydro model in to GIS software and (2) Recipient stakeholder – decision maker integration. As well considering the importance of sustainable solution provide for urban flood management, work proposed to select "Interaction" option of stakeholder-decision maker integration.

Then when automating, software developer can utilise the complex GIS processes in GIS software for carryout the processes of hydrological calculations, trusting the accuracy of the base GIS software outputs.

As well to facilitate the optimization of recipient stakeholder, software developer has to be more emphasises on customising a trial-and-error facility for inputs and outputs to and from the models.

VI. CONCLUSION

The software sustainability is depending on the way the software assists decision makers/policy makers to arrive sustainable decision in urban flood management.

Then to provide such facility, the software should capable to facilitate recipient stakeholder's requirements optimization with decision maker's requirements.

Hence the software developer need a better understanding about the processes & data integration and recipient stakeholder influence on sustainable decision making.

Therefore when develop software for policy making or public decision making which uses multiple complex processes, the development effort should realised the process integration limitations and recipient stakeholder influencing inputs and outputs in the planning stage of the software development life cycle.

The results are formulated through evaluating the experience in HydroGIS tool development activities against the literature review. Then the finding is valid and limited to hydro-GIS tool development for urban flood management. However based on the literatures reviewed the upper limitation can be increased to multi-stakeholder water resource management decision making.

The present work highlights the importance of studying the "User" as not only software operator but also recipient stakeholders in the term of sustainability of the software use in practical scenario.

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REFERENCES

Alcaraz, M., Vázquez-Suñé, E., Velasco, V., & Criollo, R. (2017). A loosely coupled GIS and hydrogeological modeling framework. *Environmental Earth Sciences, Springer,* 76(382). https://doi.org/10.1007/s12665-017-6709-3

Arnstein, S. R. (1969). A Ladder Of Citizen Participation. *Journal of American Institute of Planners,* 35(4), 216–224. https://doi.org/10.1080/01944366908977225

Becker, C., Chitchyan, R., Duboc, L., Easterbrook, S., Penzenstadler, B., Seyff, N., & Venters, C. C. (2015). Sustainability Design and Software: The Karlskrona Manifesto. *Proceedings of the 37th International Conference on Software Engineering, 2,* 467–476. https://doi.org/10.1109/ICSE.2015.179

Comair, G. F., McKinney, D. C., Maidment, D. R., Espinoza, G., Sangiredy, H., Fayad, A., & Salas, F. R. (2014). Hydrology of the Jordan River Basin: A GIS-Based System to Better Guide Water Resources Management and Decision Making. *Water Resources Management,* 28(4), 933–946. https://doi.org/10.1007/s11269-014-0525-2

EC. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal of the European Parliament,* L327(September 1996), 1–82. https://doi.org/10.1039/ap9842100196

Gray, S., Paolisso, M., Jordan, R., & Gray, S. (Eds.). (2017). *Environmental Modeling with Stakeholders.* Springer. https://doi.org/10.1007/978-3-319-25053-3

Henriksen, H. J., Refsgaard, J. C., Hojberg, A. L., Ferrand, N., Gijsbers, P., & Scholten, H. (2009). Harmonised principles for public participation in quality assurance of integrated water resources modelling. *Water Resources Management,* 23(12), 2539–2554. https://doi.org/10.1007/s11269-008-9395-9

Huang, B., & Jiang, B. (2002). AVTOP: A full integration of TOPMODEL into GIS. *Environmental Modelling and Software,* 17(3), 261–268. https://doi.org/10.1016/S1364-8152(01)00073-1

Mostert, E. (2003). The challenge of public participation. *Water Policy,* 5, 179–197.

Mysiak, J., Giupponi, C., & Rosato, P. (2005). Towards the development of a decision support system for water resource management. *Environmental Modelling and Software,* 20(2), 203–214. https://doi.org/10.1016/j.envsoft.2003.12.019

Penzenstadler, B., Femmer, H., & Richardson, D. (2013). Who is the advocate? Stakeholders for sustainability. *In roceedings of the 2nd International Workshop on Green and Sustainable Software (GREENS '13)* (pp. 70–77). San Francisco, California: IEEE Press Piscataway, NJ. https://doi.org/10.1109/GREENS.2013.6606424

PMBOK® Guide – Sixth Edition. (2017). *PMBOK® Guide – Sixth Edition. Stakeholder Needs and Requirements.* Retrieved from https://www.pmi.org/pmbok-guide-standards/foundational/pmbok/sixth-edition

Pradeep, R. M. M., & Wijesekera, N. T. S. (2011). *Tool Development for Dynamic GIS Application for Watershed Management Case Study of the Thimbirigasyaya Ward of the Colombo Municipal Council Area Tool Development for Dynamic GIS Application for Watershed Management.* University of Moratuwa.

Pradeep, R. M. M., & Wijesekera, N. T. S. (2012). GIS Tool to Mitigate Urban Flash Floods Through Capturing Land Allotment Modifications and Incorporating Conceptual Detention Pit. In *ITRU 2012.* Moratuwa: Universiry of Moratuwa.

SEBoK contributors. (2015). Stakeholder Needs and Requirements. Retrieved July 22, 2018, from http://www.sebokwiki.org/w/index.php?title=Stakeholder_Needs_and_Requirements&oldid=51430

Stuart, N., & Stocks, C. (1993). Hydrological modelling within GIS: an integrated appraoch. In *Application of GIS in Hydrology and Water Resources: HydroGIS 93* (pp. 319–329). Vienna: IAHS.

Sui, D. Z., & Maggio, R. C. (1999). Integrating GIS with hydrological modeling: Practices, problems, and prospects. *Computers, Environment and Urban Systems,* 23(1), 33–51. https://doi.org/10.1016/S0198-9715(98)00052-0

Venters, C. C., Capilla, R., Betz, S., Penzenstadler, B., Crick, T., Crouch, S., … Carrillo, C. (2018). Software sustainability: Research and practice from a software architecture viewpoint. *Journal of Systems and Software,* 138, 174–188. https://doi.org/10.1016/j.jss.2017.12.026

Voinov, A., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., … Ramu, P. (2016). Modelling with stakeholders - Next generation. *Environmental Modelling and Software,* 77(January), 196–220. https://doi.org/10.1016/j.envsoft.2015.11.016

Weiler, M., & Beven, K. (2015). Do we need a Community Hydrological Model? *Water Resources Research COMMENTARY*, 51, 7777–7784. https://doi.org/10.1002/2014WR016731.Received